REPORT DOCUMENTATION PAGE

Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
05-05-2015	Final Report	28-Apr-2009 - 27-Apr-2011

4. TITLE AND SUBTITLE
Final Report: Improved Measurement System for Atmospheric Studies

5a. CONTRACT NUMBER
W911NF-09-1-0207

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
611103

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHORS
Yannick Meillier

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
University of Colorado - Boulder
3100 Marine Street, Room 479
572 UCB
Boulder, CO 80309 -0572

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSOR/MONITOR'S ACRONYM(S)
ARO

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
55570-EV-RIP.1

12. DISTRIBUTION AVAILIBILITY STATEMENT
Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT
See attached.

15. SUBJECT TERMS
Final Report

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
UU	UU	UU	UU		Yannick Meillier
					19b. TELEPHONE NUMBER 303-492-4766

Standard Form 298 (Rev 8/98)
Prescribed by ANSI Std. Z39.18

Report Title

Final Report: Improved Measurement System for Atmospheric Studies

ABSTRACT

See attached.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations:

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received   Book

TOTAL:

Received   Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: ......

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:......

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:......

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):......

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:......

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense ......

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: ......

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME
Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

See attached.

Technology Transfer

Army TLS

Yannick Meillier

Contents

1 Budget

Permanent Equipment

(1) Basic Meteorological Payload System

(1) Data Radio Transmission module Imat radiosonde (transmitter) Radio receiver Software modem for data archiving/display Assembly and Interfacing Labview coding for data display		$10,000
(1) Thermistor/humidity sensors module		$600
(1) Position & Orientation module GPS Compass and tilt sensor Signal conditionning circuit board		$500
(1) Data acquisition module (digitizer)		$2,100
(1) Instruments housing package		$1,500
(1) Pitot tube velocity sensor module		$1,500
(1) Power units (battery modules and conditionning)		$300
	Sub Total:	**$16,500**

(5) Turbulence Payload System

(5) Pitot tube velocity sensor module		$6,400
(5) Thermistor/humidity sensors module		$700
(5) hotwire/ cold wire temperature/velocity cards		$2,100
(5) Position & Orientation module GPS Compass and tilt sensor Signal conditionning circuit board		$2,800
(5) Data acquisition module (digitizer)		$7,800
(5) Instruments housing package		$7,100
(5) Power units (battery modules and conditionning)		$1,500
(5) Modules assembly/interfacing		$1,700
(20) Fine wire Probes (4 per turbulence package)		$8,000
	Sub Total:	**$38,100**

Lifting Platforms and related equipment

(1) High wind lifting platform: 24 cu meter Helikyte
(1) Fairweather lifting platform: Aerodynamic blimp
(1) Higher strength tether for helikyte
(2) Deflation device

	Sub Total:	**$23,800**
	TOTAL	**$78,400**
		5/09

To-Do list

1.1 Winch

- Machine shop taking care of its fabrication.

1.2 Turbulence Payloads (3)

- HW
- CW
- DAQ
- Sparkfun
- Thermistor cards
- Pitot
- Serial interface
- Power connection card
- GPS
- Compass module
- Pitot tube
- Probes
- Batteries
- Tubes
- Caps
- Rings
- Bare board
- Misc connectors and wires
- vinyl tubing for pitot
- Screws/standoffs
- coax cable
- Probe mount material (U-channel, tubes, brackets)
- Wind Vane
- Harness (Kevlar rods, eye bolts, thimbles)

1.3 Trailer

1.4 Lifting platforms

- Helikyte/Blimp (Budgeted for 1 of each.)
- Fast deflation device
- LED flashing lights

1.5 Misc. off the shelf orders

- Batteries (budgeted for 10)
- Battery cables
- Inverter
- Heavy duty cable (battery to winch) –gage to be determined-
- 110V/15A plug – cable – to winch plug (for direct hookup to grid)
- Loading ramps

1.6 Calibration of pitots: where to do?

1.7 IDL processing code

1.8 Training

2 System Overview

2.1 Introduction

The Cooperative Institute for Research in Environmental Sciences (CIRES) Tethered Lifting System (TLS) is a specialty-designed state-of-the art tethersonde system that offers unique measurement capabilities for the study of the structure, dynamics, and turbulent properties of atmospheric boundary layers. The TLS offers unique high precision and high quality data that other standard atmospheric research measurement systems such as instrumented aircrafts, meteorological towers, rawinsondes, remote sensors, and standard tethersonde systems cannot provide as they are limited by either a lack of spatial and temporal resolution, vertical coverage, or sensitivity to small scale turbulent processes.

The TLS uses tethered aerodynamic blimps and precision-powered winches to loft one or more specialty-designed meteorological payloads that collect high-quality *insitu* measurements of temperature, windspeed, humidity, and turbulence. The lifting platform can be parked at specific heights to gather data at constant altitude in a similar fashion to instrumented towers, or it can be used in profiling mode to collect unique high resolution profiles from the ground up to 3 kilometers above ground (or higher). The winches were designed specifically for atmospheric research. It offers precise and constant profiling speeds for accurate profile measurements and a maximum reel-in rate of 3 m/s for emergency pull-downs. Thanks to their wheel-mounted design, the battery powered winches are highly portable facilitating field operations and ensuring quick deployment times (15 minutes or less). The TLS state-of-the-art turbulence payloads use fast-response fine-wire probes to measure temperature and windspeed at a 1 kHz sampling rate. Small-scale turbulence statistics, the energy dissipation rate ε and temperature structure constant C_T^2, are then estimated with high accuracy from the velocity and temperature spectra respectively. The fast-response and high sensitivity of the turbulence probes combined with the low noise performances of the custom-built electronic circuits allow to resolve extremely low levels of turbulence ($\varepsilon=10^{-8}$ m^2s^{-3} and $C_T^2=10^{-7}$ $K^2m^{-2/3}$) corresponding to fluctuations of less than 1 mC and 1 mm/s which, to the knowledge of the author, no other system is capable of. The use of the precision-controlled winches with the turbulence payloads then permit high quality profile measurements of temperature, velocity, and turbulence at vertical resolutions of 0.2 m or less. The TLS also records other standard meteorological quantities such as atmospheric pressure, wind direction, humidity, as well as payload altitude, latitude, and longitude. It is important to note that the TLS was designed for fair weather conditions and was never tested at wind speeds greater than 20 m/s. Included in the budget is the purchase of a high-wind lifting platform to operate in such regimes. The turbulence payloads are also not suited for operation in rain or snow.

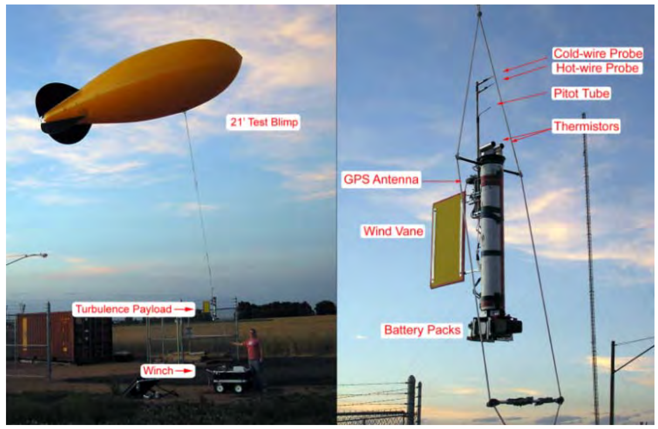


Figure 1: Left: Picture of the TLS aerodynamic blimp, winch, and turbulence payload. Right: A close-up view of a turbulence payload (prototype).

The TLS provides unique measurement capabilities to assist and further research on a wide range of applications such as improvements of numerical weather prediction and transport and diffusion models, basic boundary layer meteorology research, acoustics, EM propagation, and possibly for support in field operations. The TLS has to this date produced unique measurements in the nighttime stable boundary layer, a critical region for homeland security because of the increased risk of transport and dispersion of hazardous releases in this regime. Results to date include:

- the discovery of extreme temperature and turbulence gradients capping the boundary layer and of narrow regions of both high and low turbulence in the residual layer (Balsley B. B., et al., 2003, 2006)
- high resolution details of ducted gravity waves hundreds of meters above the earth's surface (Fritts et al. 2003)
- evidence of the modulation of turbulence intermittency by gravity waves (Meillier et al 2006)
- the identification of a very thin layer of cooler air at the top of the stable boundary layer which is lower than the temperature inversion (Frehlich et al. 2006)
- the discovery of upward surges of air associated with surface winds moving up a gully (Balsley et al. 2002)
- validation of lidar-based measurements of energy dissipation rate profiles in urban and suburban environments (Frehlich et al. 2006, Frehlich et al. 2008)
- the study of the effect of spatial averaging on the statistics and interpretation of the gradient Richardson number (Balsley et al. 2008)
- prediction of model parameterization for stable conditions, and verification of new theories for stably stratified turbulence (Riley and Lindborg 2008; Frehlich et al. 2008),
- the demonstration the large variability of turbulence profiles in a suburban canopy compared to lidar derived profiles (Frehlich et al. 2006, 2008).

Note that although the TLS is currently used for high resolution measurements of temperature, wind speed, and turbulence, the system could be used to lift payloads of different nature such as 3D-sonics or lightweight chemistry sensors, and could be used in battlefield operation to lift high altitude military radio relays.

2.2 TLS Capabilities and performances

The specialty designed turbulence payload, pictured on the right panel of Figure 1, uses fine-wire cold-wire (CW) and hot-wire (HW) sensors to measure with high accuracy and high temporal resolution (1 kHz) the stream-wise fluctuations of temperature and wind speed respectively. Hot-wire velocity is calibrated to an absolute accuracy better than 0.03 m/s and a slope-accuracy better than 0.1%, and the cold-wire temperature is calibrated to an accuracy better than 0.1 C and a slope accuracy better than 0.3% using pitot tube and thermistor sensors respectively. The temperature structure constant C_T^2 and energy dissipations rate ε are computed by fitting theoretical models to the temperature and velocity spectra. The models assume the small-scale turbulence to be locally homogeneous and isotropic and that Taylor's frozen flow hypothesis is valid. These conditions are well satisfied for high Reynolds numbers regimes and for estimates from short time intervals (Frehlich et al. 2003). The high sensitivity of the TLS turbulence measurements is ideally suited for operation in the low turbulence regimes that characterize nocturnal boundary

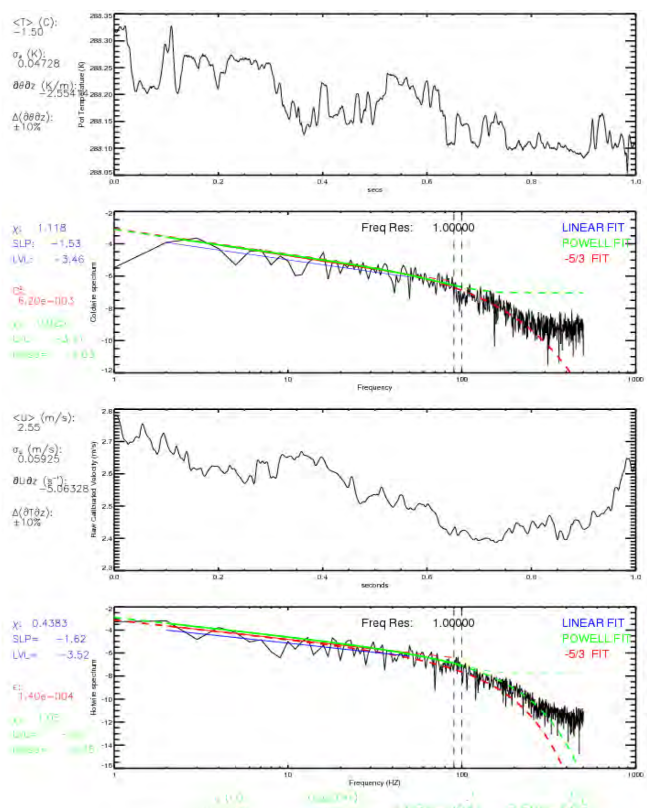


Figure 2: 1-second time series of temperature (top panel) and wind speed (3rd panel from top) and their corresponding spectra and fits to theoretical models.

layers. Additionally, accurate spectral estimates of C_T^2 and ε from as little as 1-second spectra provide the high temporal and high spatial resolutions required to resolve the rapidly changing and highly variable vertical structure of the atmospheric boundary layer, and to resolve fine-scale as well as short- lived turbulent structures and processes.

Fig.2 illustrates fits of theoretical models to one-second spectra of temperature and velocity for the calculation of C_T^2 and ε respectively. Such models assume a Gaussian cut-off function for the high–wavenumber region of the three dimensional spectrum, the -5/3 power law of turbulence in the inertial range, the rollover of spectral power at the Kolmogorov microscale, and for temperature, the Hill bump in the inner scale region of the spectrum. Thanks to the high bandwidth (1 kHz) and low noise properties of the electronics, 1-second estimates of C_T^2 and ε are achieved with accuracies better than 15%. In addition to C_T^2 and ε, other parameters such as the Reynolds number, Buoyancy Reynolds number, turbulent Froude number, gradient Richardson number, Ozmidov scale, and temperature inner-scale, are also determined.

The state-of-the art winch was specifically designed to facilitate field operations. It is mounted on wheels to improve portability and ease of deployment, can be powered from high power batteries for operation in remote locations, and provides a maximum reel-in rate of 3 m/s for emergency pull-downs. The winch was also designed to provide constant and precise profiling rates ranging from a fraction of a m/s up to ~3 m/s. The winch control box can be programmed to set predetermined flight patterns thus allowing continuous unmanned profiling for the duration of the lifetime of the turbulence payloads and winch batteries (14 hours).

Figure 4 shows typical TLS high resolution profiles of temperature, wind speed, temperature structure constant, and energy dissipation rate. The turbulence profiles capture the characteristic variability of atmospheric turbulence, display various small-scale structures and layers sometimes delineated by very sharp gradients of a decade or more over less than 1 meter, and allow to identify the top of the boundary layer much more accurately than estimates that are based on the mean profiles of temperature or windspeed. Observations of sharp interfaces and small-scale structures similar to those shown in Fig.4 would typically be missed by instruments with larger spatial averaging, coarser vertical resolutions, or of a lesser sensitivity, such as radiosondes, remote sensors (lidars, radars), and instrumented towers.

Figure 3: Pictures of the winch with the lid open (Left) and in its transport configuration with push handles, wheels, and jack (Right). The jack is used to remove the wheels and drop the winch on the ground (540lbs/250kg).

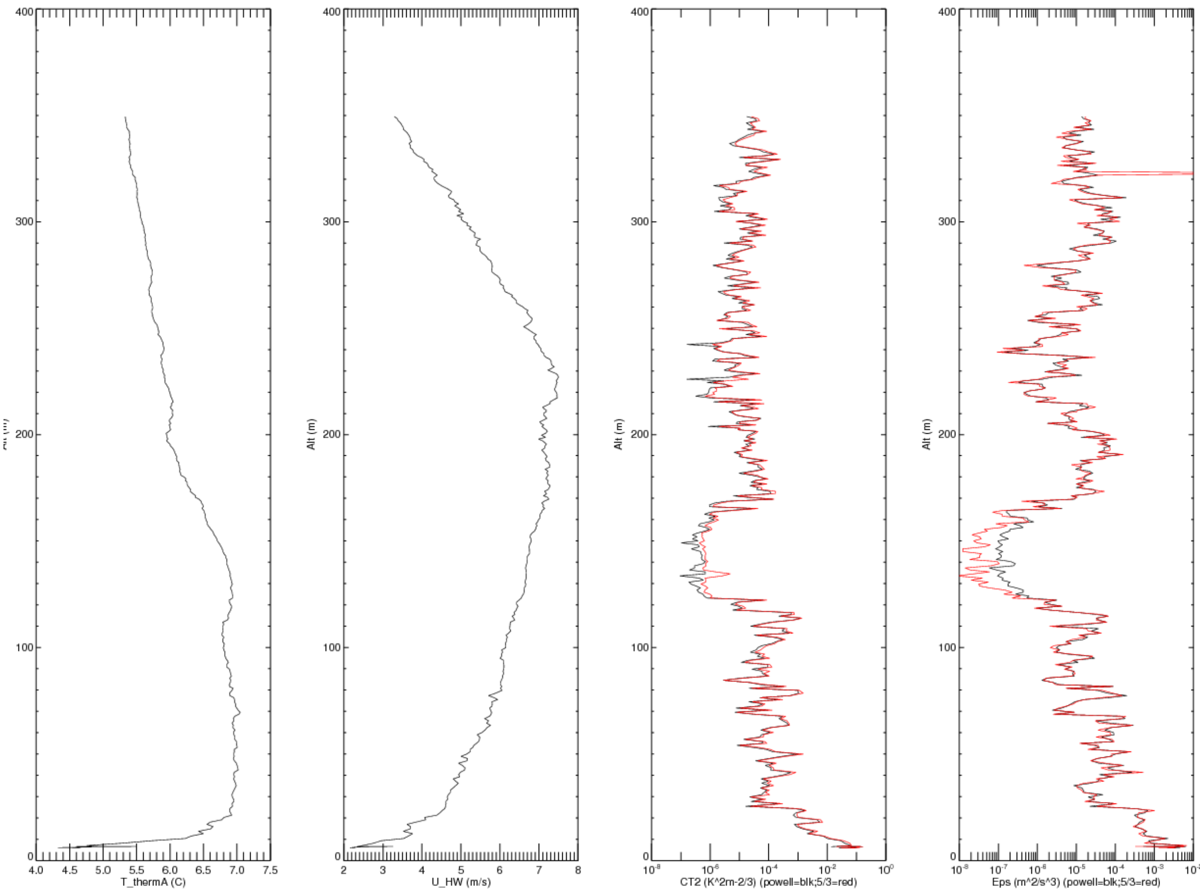


Figure 4: High resolution profiles of temperature (left panel), windspeed (2nd panel from the left), temperature structure constant (3rd panel from the left), and energy dissipation rate.

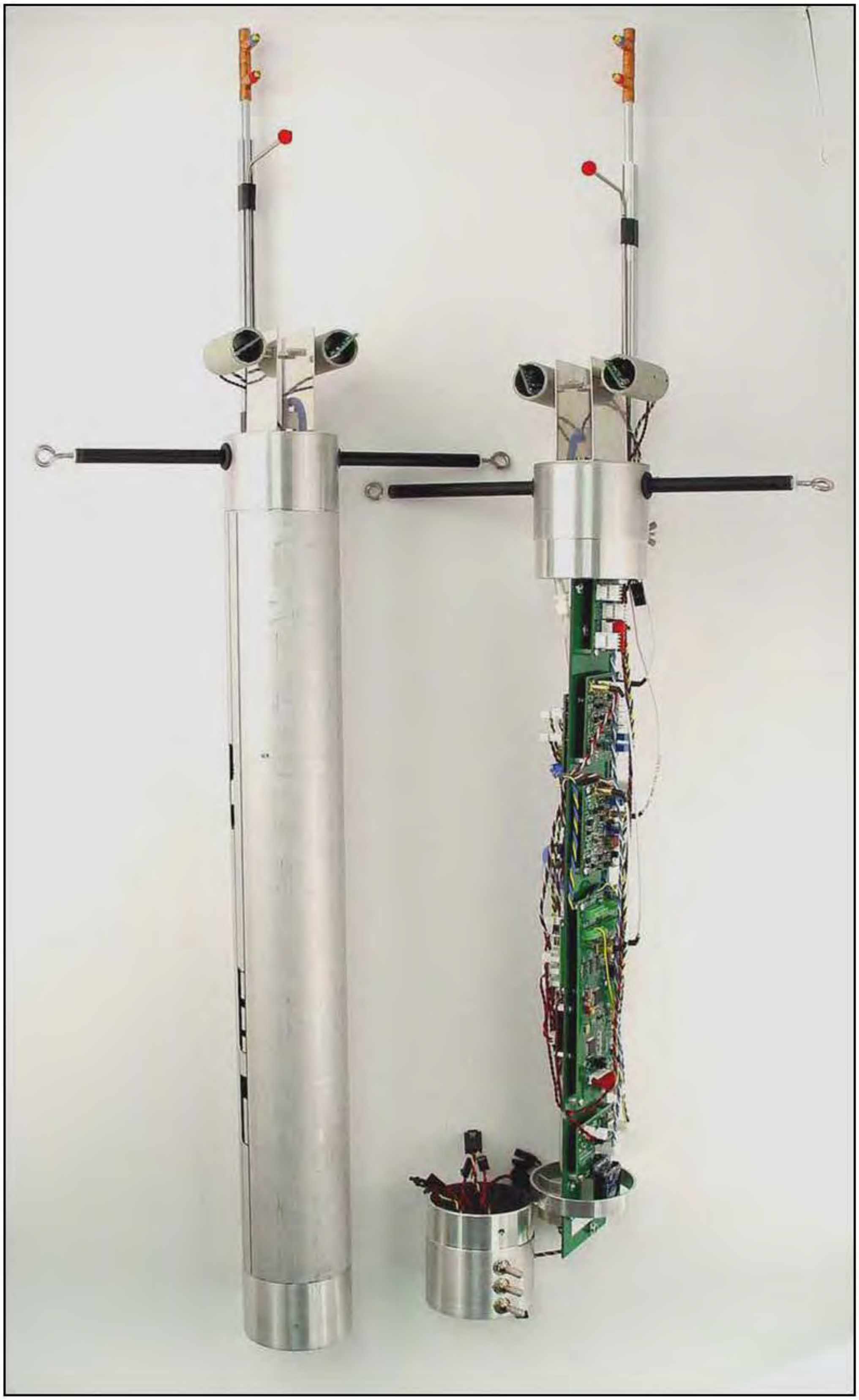


Figure 5: Turbulence Payload

The following documentation presents information about:

- system components
- instructions for testing and quality control of each module of the turbulence payload
- operation instructions
- data calibration procedures

3 Turbulence Payload Components

The turbulence payload is composed of a number of individual circuit modules assembled onto a main support board and housed inside the aluminum tubing. We adopted a modular approach so that each card could be tested and evaluated individually and to facilitate potential future improvements on a per card basis.

Each turbulence payload uses one hot-wire (HW) anemometer circuit and one cold-wire (CW) thermometer circuit for highly sensitive measurements of wind speed and temperature respectively. Each of these cards is connected via mini-coax cables to fine wire probes (DANTEC type fine wire probe) mounted to outside the aluminum tube. Each card's output is then sent to the high frequency input channels of the Data AcQuisition card (DAQ) via either mini-coax cables (default) or standard wires. The HW and CW cannot be calibrated ahead of time to provide temperature and velocity signals because the properties of the fine wire probes change with time. Therefore, supporting calibrated windspeed and temperature sensors are flown in conjunction to the HW and CW sensors for their calibration. These sensors are either calibrated ahead of time or come already factory calibrated. For windspeed measurements, we use a custom-built circuit that measures the dynamic pressure of the small pitot tube that is flown next to the HW probe. For our reference temperature measurement, we use custom thermistor cards that use a combination of thermistor bead sensors and solid state temperature sensors. In addition to the HW and CW velocity and temperature sensors, other modules measure: the wind direction and the package's pitch and roll angles, GPS altitude, latitude and longitude, absolute pressure, and humidity.

For logging the data, a total of two digitizers are used. The DAQ is the main digitizer. It records the sensitive analog signals of the HW, CW, thermistor (temperature and humidity), and pitot card (absolute pressure, dynamic pitot tube pressure, and internal package temperature signals). All in all, the DAQ provide 16 0-2.5V channels to be digitized at 100Hz and 2 HF channels digitized at 1kHz (for the HW and CW). A second digitizer, the 'Sparkfun' datalogger, logs a stream of serial data generated by the serial interface card. The serial interface merges the altitude, latitude, and longitude data of the GPS with the yaw, pitch and roll data of an analog 3D compass together with a counter that is generated by the DAQ and that is used to synchronize the sparkfun data to the DAQ data (the counter is digitized by both digitizers). The reason for digitizing these data on a different data acquisition card is that serial data have a potential for interfering with the sensitive analog data of the HW and CW cards if logged on the same device. Plus logging these extra data on a different datalogger simplifies the digitizing pattern used by the DAQ (does not have to log extra data). Data from the DAQ are archived onto a flash card and data from the sparkfun onto an SD card.

The HW and CW cards, as well as the other modules of the turbulence payload, are powered with 7 V lithium batteries (two 3.5V lithium ion batteries put in series). Some modules like the HW and CW require a dual power supply, while some other like the DAQ are only single supply. The battery packs are housed inside the bottom aluminum tube cap. Separate battery packs are used for: 1/ the HW & CW cards, 2/ the two digitizers (DAQ and sparkfun digitizer), 3/ a solenoid switch, and 4/ the thermistor, pitot, GPS, and serial interface cards.

Following is a better overview of each module of the turbulence payload:

3.1 Data acquisition card (DAQ)

Used for logging the analog signals generated by the other modules onto a Compactflash card (formatted as FAT). This includes the HW and CW, the temperature and humidity signals from the two thermistor cards and the data generated by the pitot card (absolute pressure, internal temperature, pitot tube dynamic pressure). The DAQ also generate a digital counter that is sent to the sparkfun digitizer for synchronization purposes.

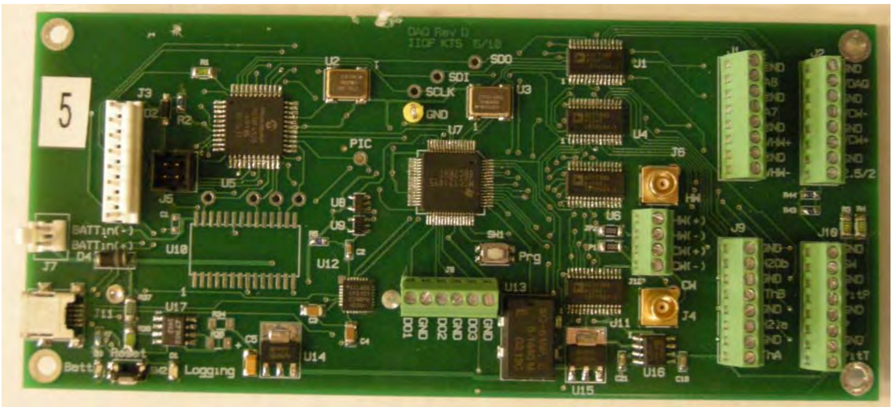


Figure 6: Data Acquisition Card (DAQ)

The DAQ also generates and digitizes a switch signal that controls a solenoid switch used with the pitot card (more details below). The switch signal, outputted by the DO1-4 channels, is high (2.5V) for 3 seconds and low (0V) for 57 seconds. Finally a reference 2.5V signal generated onboard the DAQ is digitized to check for voltage drifts related to warm-up times or to check for temperature effects.

The DAQ contains a total of 4 ADC chips (AD738). At 100Hz, each chip can record 8 signals with a 16bits effective resolution. At 1 kHz, each chip can record just one signal at 16bits. So the DAQ includes one chip for the CW, one for the HW, and 2 chips for logging up to 16 signals at 100Hz. Typically, the repartition of channels is:

- LF chip1 channel1 (A1): Pitot card temperature.
- LF chip1 channel2 (A2): absolute pressure.
- LF chip1 channel3 (A3): pitot pressure signal.
- LF chip1 channel4 (A4): hardwired to the switch signal generated by the DAQ.
- LF chip1 channel 5 through 8 (A5 –A8): not used.

- LF chip2 channel 1 (A9): onboard voltage reference (voltage divided by 2).
- LF chip2 channel 2-3 (A10-A11): not used.
- LF chip2 channel 4 (A12): thermistorA’s TMP36 signal (temperature).
- LF chip2 channel 5 (A13): not used.
- LF chip2 channel 6 (A14): humidity sensor of thermistor B.
- LF chip2 channel 7 (A15): thermistor signal of thermistor card A.
- LF chip2 channel 8 (A16): thermistor signal of thermistor card B.

The counter is recorder only once at the end of each 512 bytes sectors. See the description of the DAQ sampling pattern for more details.

3.2 Cold-wire card (CW)

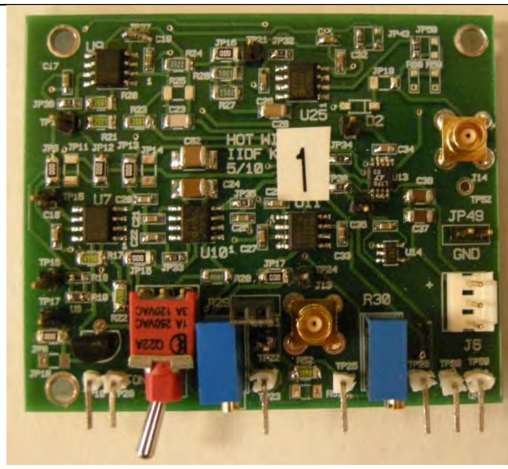


Figure 7: HW card

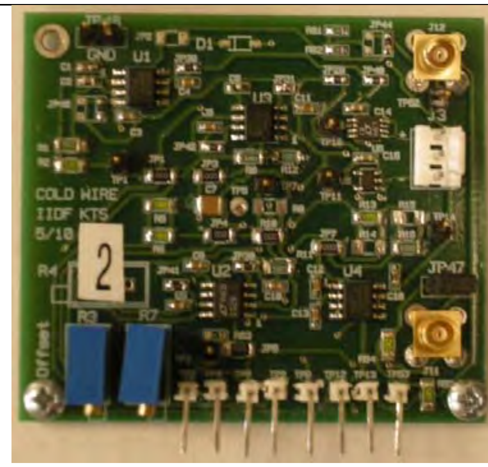


Figure 8: CW card

The cold wire card is a low-noise signal conditioning card designed to process with high accuracy the rapidly fluctuating and highly sensitive signal of the fine wire probe. This card is what limits the degree of accuracy and sensitivity of the CW temperature measurements since the sensor itself has a flat bandwidth all the way to many kHz and an extremely high sensitivity to the smallest temperature fluctuations. This card is designed to produce a signal with a 30C dynamic range that will fit within the 0-2.5V input voltage range of the DAQ, while keeping the noise at a minimum level so as to resolve as much of the fine scale fluctuations.

A CW works on the same principles as a hot wire anemometer. A constant current is applied to the terminals of a fine wire probe (5 micron thick, ~1/16 in. long tungsten wire) connected to the board via a mini-coax cable (bottom MCX receptacle in Figure 8). The current is low enough to keep the tungsten wire of the probe cool so that the circuit does not act as a hot wire. Changes in temperature induce changes of resistance of the wire according to the temperature coefficient of the material of the wire. At room temperature the wire has a resistance of ~5 ohms. A bridge circuit measures the resulting small voltage changes which are then amplified with a gain of ~2000 (in two stages throughout the circuit) to generate a signal with approximately a 30C dynamic range across a 2.5 voltage range (DAQ's input voltage range is 0-2.5V). The CW card noise floor is set by the noise properties of the front end LT1028 opamp. This level times the gain used to set the 30C dynamic range over 2.5V determines the smallest fluctuations that can be resolved (calculations shown later).

The signal still needs to be calibrated in post using another reference temperature signal (the thermistor card). Calibrations cannot be hardwired as the properties of the fine wires of the probe changes with time constantly. So this is why concurrent temperature (and velocity for the HW) signals are collected with less sensitive sensors that have constant calibration coefficients (calibrated in laboratory).

3.3 Hot-wire card (HW)

A hot wire anemometer is similar to a cold wire temperature sensor except that this time, a high current is sent through the wire to keep it at a high temperature. The wire is kept at a constant temperature by adjusting the current flowing through the wire as more or less heat is advected away by the varying windspeed. The wire is operated at a constant overheat ratio where the overheat ratio is the hot to cold ratio of the wire's resistance. Just like the CW signal, the HW signal is uncalibrated, a calibration that is done in post with the reference velocity signal of the pitot tube.

3.4 **Pitot card**

The pitot card uses a differential pressure sensor connected to the two ports of the Pitot tube to measure the dynamic pressure (connected to airspeed via the Bernoulli equation). Typically, one would only measure the differential pressure of the dynamic port relative to the static port of the pitot-tube. However, the gain of the differential pressure sensor has an unspecified temperature effects which needs to be calibrated out. Therefore, every minute, a solenoid switches between measuring the dynamic pressure relative to the static port (Pdynamic-Pstatic) to measuring the static port relative to itself (Pstatic– Pstatic). The offset changes with temperature and the time series of the Pstatic-Pstatic measurements collected every minutes is interpolated to 1 second data and substracted from the Pdyn-Pstatic measurement to calibrate out the effect of temperature. Dynamic pressure measurements are made for 57 seconds wile reference pressure measurements are only done for 3 seconds. The 3 seconds of data gap does not affect the calibrations since the same 3 seconds of data missing from the pitot are removed from the HW signal when performing the calibration of the HW with respect to the Pitot.

The pitot card also provides reading of absolute pressure (used for more accurate altitude measurements once calibrated with the GPS altitude), and internal temperature. The pressure sensor of the pitot card is typically calibrated only once using the NCAR wind tunnel. It then serves as our reference velocity signal to calibrate the HW.

Make sure that the output of the pressure sensor is set to 0.1V at 0m/s. 0.2V max. Otherwise, if at 0m/s the output voltage is >0.2V, a 20m/s wind will make Vout go above 2.5V which is the maximum input voltage of the DAQ ADC chips.

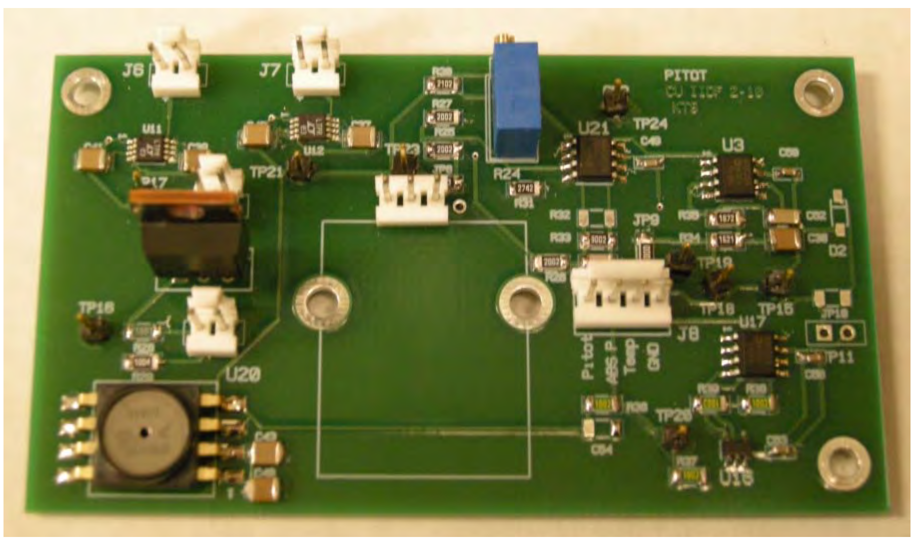


Figure 9: Pitot Card

3.5 **Thermistor card**

Each turbulence payload carries two thermistor cards. One measures temperature with both a thermistor bead and with another reference temperature sensor (TMP36). The TMP36, a factory calibrated temperature sensor with a ~3 seconds time constant, is used for the calibration of the thermistor bead. The thermistor bead has better sensitivity and time response characteristics than the standard solid-state temperature sensor, characteristics that are required for

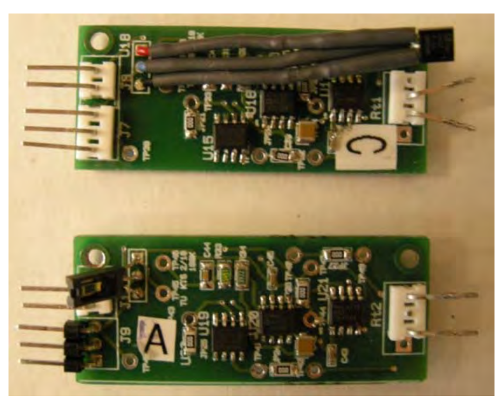


Figure 10: Thermistor cards

calibrating the CW. The thermistor beads however have drifting properties so its calibration cannot be performed in a laboratory before use. The TMP36 calibration properties however do not change with time. So the TMP36 is used to calibrate the thermistor bead, and the thermistor bead is used to calibrate the CW. The thermistor bead is preferred over the TMP36 for calibration of the CW because to get good calibrations of the CW, we need as much overlap as possible of both signals in the spectral domain. The thermistor bead being more sensitive and having a lesser time constant than the TMP36 provides more overlapping Fourier coefficients with the CW than the TMP36 does (for calibration details see section XX). The other thermistor card does not have a TMP36 sensor but instead a humidity sensor (as well as a thermistor bead). Because the thermistor beads are fragile, it is best to use two thermistor cards in case one was to be damaged.

3.6 Serial Interface card

The serial interface card is meant to merge signals from the GPS (alt, lat, lon) and digital compass (yaw, pitch, roll) into a single stream of serial data. It has optional connectors/ports to bring in additional analog signals (changes in the code loaded onto the serial card are required). This single stream of data is then sent to the sparkfun datalogger. The serial interface also includes in its data stream the counter generated by the DAQ (increments by 1 every sector i.e. 512 bytes, i.e every 0.063 sec).

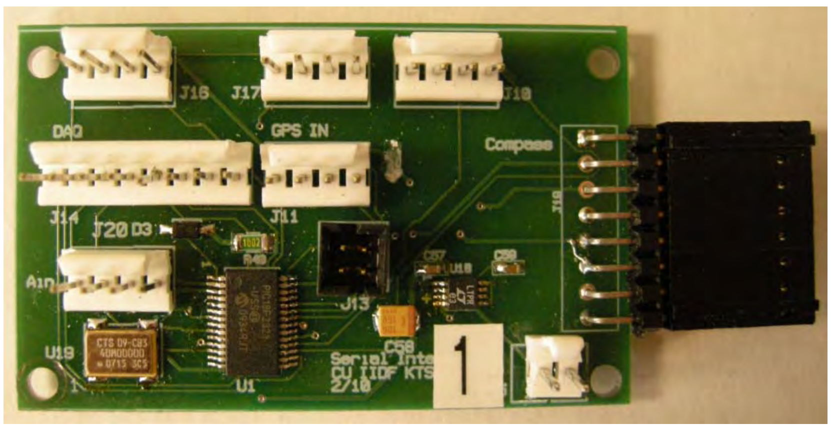


Figure 11: Serial Interface Card

3.7 Xbee Telemetry card

This module was added at the last minute to transmit data from analog signals to the ground along with altitude information from the GPS. By grabbing the thermistor and pitot tube signals, this card would permit to plot in real time un-calibrated profiles of temperature and windspeed. However, tests have revealed that the signals collected on the DAQ were contaminated by the telemetry module so it is best to not use that module with turbulence payloads. To make use of that information, a package dedicated to telemetry would have to be flown.

3.8 GPS

The GPS module is an off-the shelf product. It is connected to an external antenna via an SMB connector and coax cable.

Figure 12: GPS unit

3.9 Sparkfun digitizer

This digitizer only collects the digital data sent by the interface card. Every 5 seconds, it collects GPS information of altitude, lat, lon and DAQ counter. It then collects 5 seconds of compass data (operated at 8Hz) for a total of 40 consecutive lines of yaw, pitch, roll.

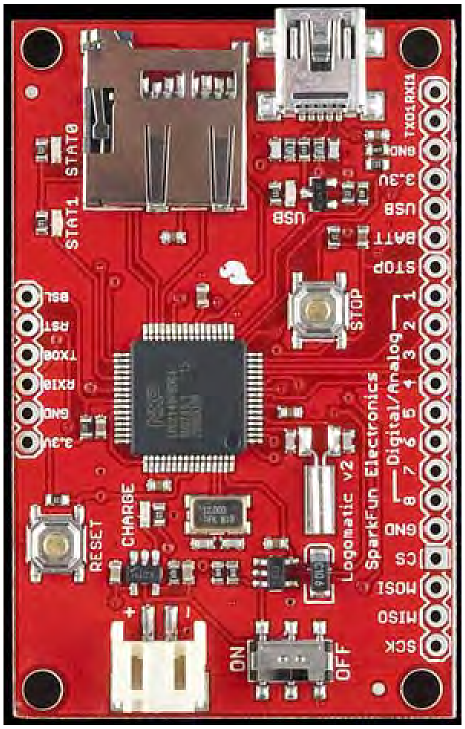


Figure 13: Sparkfun datalogger

The microSD card needs the following file on it for the datalogger to operate: LOGCON.txt

MODE = 0

ASCII = y

Baud = 5

Frequency = 100

Trigger Character = $

Text Frame = 100

AD1.3 = N

AD0.3 = N

AD0.2 = N

AD0.1 = N

AD1.2 = N

AD0.4 = N

AD1.7 = N

AD1.6 = N

Saftey On = Y

* Not the apparent typo on Saftey. It is not a typo. This is how it is on the card we've used. It might be a typo but it works this way so no need to change it.

There is also a specific procedure to follow when using a new micro-SD card. It is indeed not as trivial as formatting the SD card and loading the LOGCON.txt file on it. Before you power up your Logomatic for the first time, format the microSD card in Fat16. Then install the card into your Logomatic and turn it on. The LEDs will blink reassuringly and then go quiet. Now, turn the unit off. You will now find two files on your card, LOGCON.txt and LOG0.txt. The first is the configuration file, the second is the first logged file (empty). Replace the configuration file LOGCON.txt with the one provided or implement the changes listed above.

3.10 Batteries

The batteries are housed inside the bottom cap. There are separate battery packs for: 1/ the DAQ and sparkfun, 2) the HW and CW cards (requires +Vs and -Vs), 3) the solenoid, 4) the other modules (pitot card, thermistor card A&B, serial interface). Each battery consist of a number of 3.7V 1000mAh Lithium batteries. Two 3.7 batteries are put in series to make for a 7+V batteries. Then a number of such 7V batteries are assembled in parallel for depending on the current draw of each module. The DAQ uses three of these batteries, the CW uses two (one for +Vs and one for –Vs), the solenoid is a single 7V battery) and the battery pack for the remaining modules (thermistors, pitot, serial interface, GPS) uses two sets of 7V batteries.

Figure 14: Batteries and battery cap.

3.11 Probes

Probes are purchased from Auspex Scientific. The probes are custom fitted to an MCX connector. Those probes are made of a 5 micron tungsten wires with a resistance of roughly 5 ohms. A probe can be used with either cold-wire or hot-wire cards.

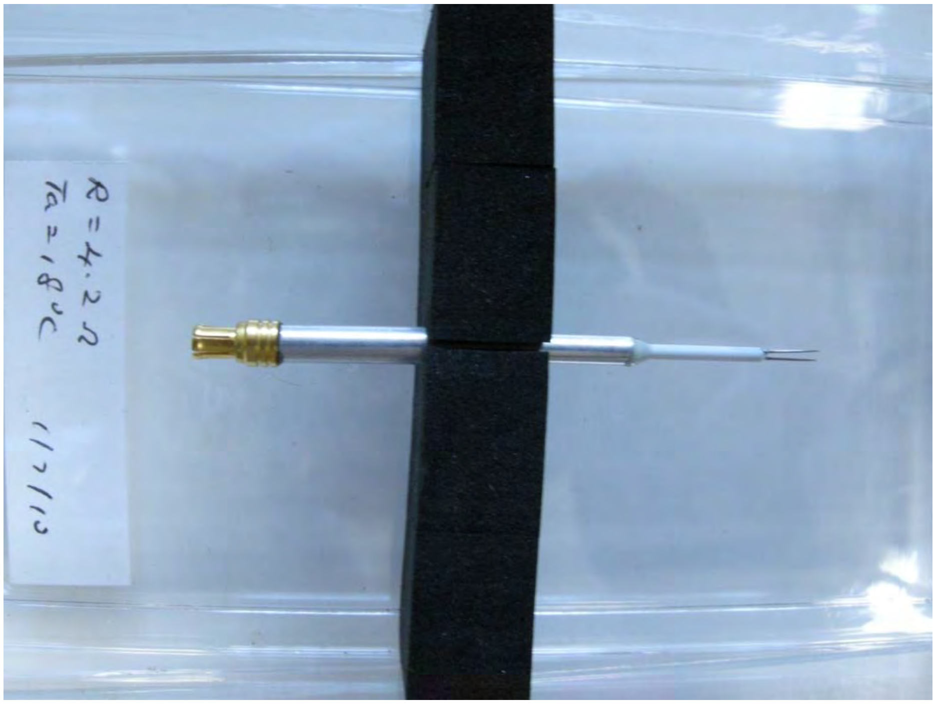


Figure 15: Probe

The standard probe is similar to a single wire Dantec Dynamics 55P11 probe (the wire section on the picture above).

The probes are purchased through Auspex Scientific who are able to deliver the probe with a custom design of ours. This uses an MCX mini coax connector and aluminum tubing for the probe to fit directly onto our probe mount. Not that the probe has two wires and the external part of the probe is therefore not ground. Special MCX plugs on the turbulence payload (outside of MCX plug not in contact with any metal part but connected to the outside conductor of an RG178 coax cable.

4 Principles of Operation

4.1 DAQ:

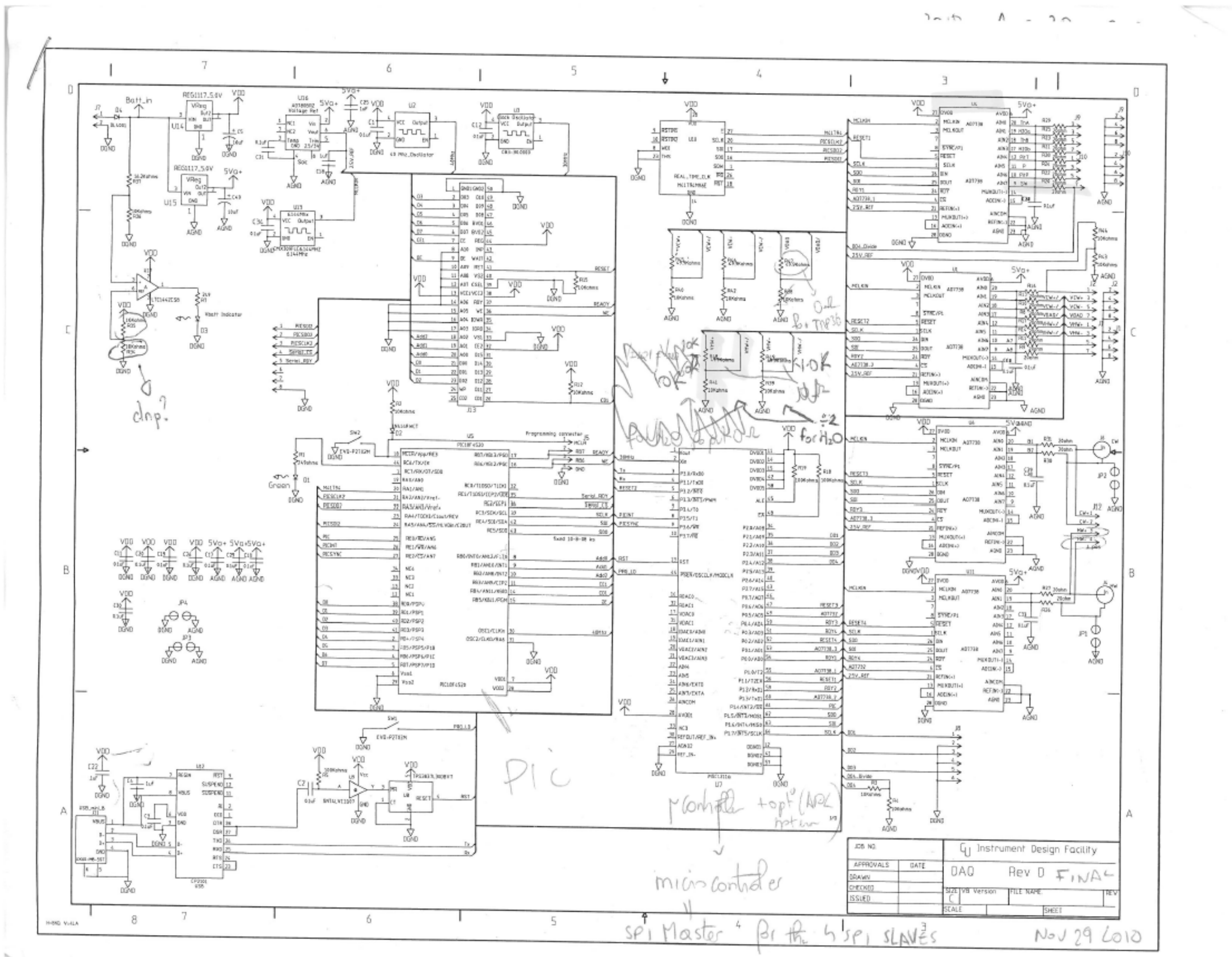


Figure 16: DAQ circuit

The DAQ uses 4 separate AD7738 Analog to Digital Converters (ADC) for logging the sensitive CW and HW signals and the other supporting signals such as the pitot tube pressure, thermistor voltages, humidity, absolute pressure, and internal temperature. A dedicated ADC chip is used for each of the HW and CW signals (1kHz sampling rate) while 2 more chips are used for logging up to 16 additional channels at a sampling rate of 100Hz.

The AD7738 ADC chips have 8 configurable single ended input channels (or 4 fully differential) with a 0-2.5V input voltage range. The absolute maximum rating for the input voltage of the analog channels is -0.3V to +7V.

Initially, the ADC used for digitizing the HW and CW signals at 1 kHz were single channel ADCs (AD7732). Later, new ADC came out (AD7738) which offer a 16bit peak to peak resolution with a channel switching of up to 8.5kHz. Therefore, both CW and HW signals could effectively be digitized by the same ADC but since the DAQ layout was designed for having one chip for each HF chip, we did not change the board when these new more performant chips became available.

The Low frequency signals (LF) are thus digitized at a sampling rate of 100Hz. Since we have two ADC chips for the LF signals with each chip having 8 single-ended input channels, we can sample up to 16 channels at 100Hz.

SPI is used as the protocol of communication between the ADCs and another microcontroller (MSC1211a, U7). This micro-controller act as the Master SPI, grabbing the signals from the 4ADC chips sequentially to produce the single stream of serial data that ultimately get written to a flash card.

Because the microcontroller is operating at a fast rate (4kHz as each of the 4 ADCs run at 1 kHz, with the 2 ADCs dedicated to the LF channels sampling 8 channels every 0.001sec) and because writing to the flash card takes more time than 0.25ms, the microcontroller cannot finish transferring data to the flashcard in less than 0.25ms. Indeed the microcontroller cannot read and write at the same time and while it is busy writing data to the flash card, it cannot continue digitizing. Writing to the Flash card is fast, but not fast enough to be done before the MASTER SPI needs to get the next sample of the four 1 kHz data (1 kHz from HW, 1kHz from CW, 1kHz from the LF chip1 which samples 10 channels at 100Hz i.e. 1kHz).

Therefore, a 3rd microcontroller capable of faster communications with the 2nd microcontroller is used to receive the data from the Master SPI. The transfer between the master SPI and the PIC is very fast allowing to digitize the data without any interruption. While the micro-controler is collecting the next batch of data, the PIC (2nd microcontroller) writes to the card. Because the PIc is busy writing, the ucontroller buffers data until the PIC is ready to receive data again.

While the micro-controller is the device you program to define the sampling pattern, the pic is the one you program to decide of the size of the swap file. As you collect data, you do not get a file of a continuously growing size. Instead, the data collected on the flash card will always fit within a file of fixed size called swap file, and depending on how long you collect data for, the swap file might or might not get full. The size of the swap file can be changed to whatever size the flash card itself allows (e.g. 2 Gb) but it is unnecessary to create such large files when only a few % of that size is needed.

Digitizer sampling pattern:

The serial data of the DAQ are recorded onto the flash card with a repeatable pattern. The CFDATA.DAT binary file can be previewed with the WinHex free utility.

The data are written in Hex (0,1,2,…,9,A,…,F) and each sample is a 2-byte word since a byte is 8 bit and the data are recorded with a 16 bit resolution.

A byte is 8 bits (e.g. 01001101) and in Hex a byte therefore has 2 characters. e.g. 8A, AF, 45, …

Because we are digitizing a 16 bit signal (16 bits = 2^16 = 256*256 = 65,536), a 16 bit hex sample looks like: AE59 (two 8 bit hex samples) and any sample can be converted to the voltage reading. E.g., AE59 corresponds to:

$$\frac{2.5\text{V}}{2^{16}}\left(9\times 16^{0}+\ 5\times 16^{1}+\ 15\times 16^{2}+10\times 16^{3}\right)=1.71238\,V$$

The data are written to the flash card in blocks of 512 bytes with the last 4 bytes being used to write down a block counter (increment by 1), and the 4 bytes before that being used for a times stamp (no longer used and left empty because of problems with the real time clock).

First the sample from channel 1 of LF chip1 (LF1_1) is written, then the first channel of the second LF chip, then sample of the HF chip1, and finally the sample of HF_chip2.

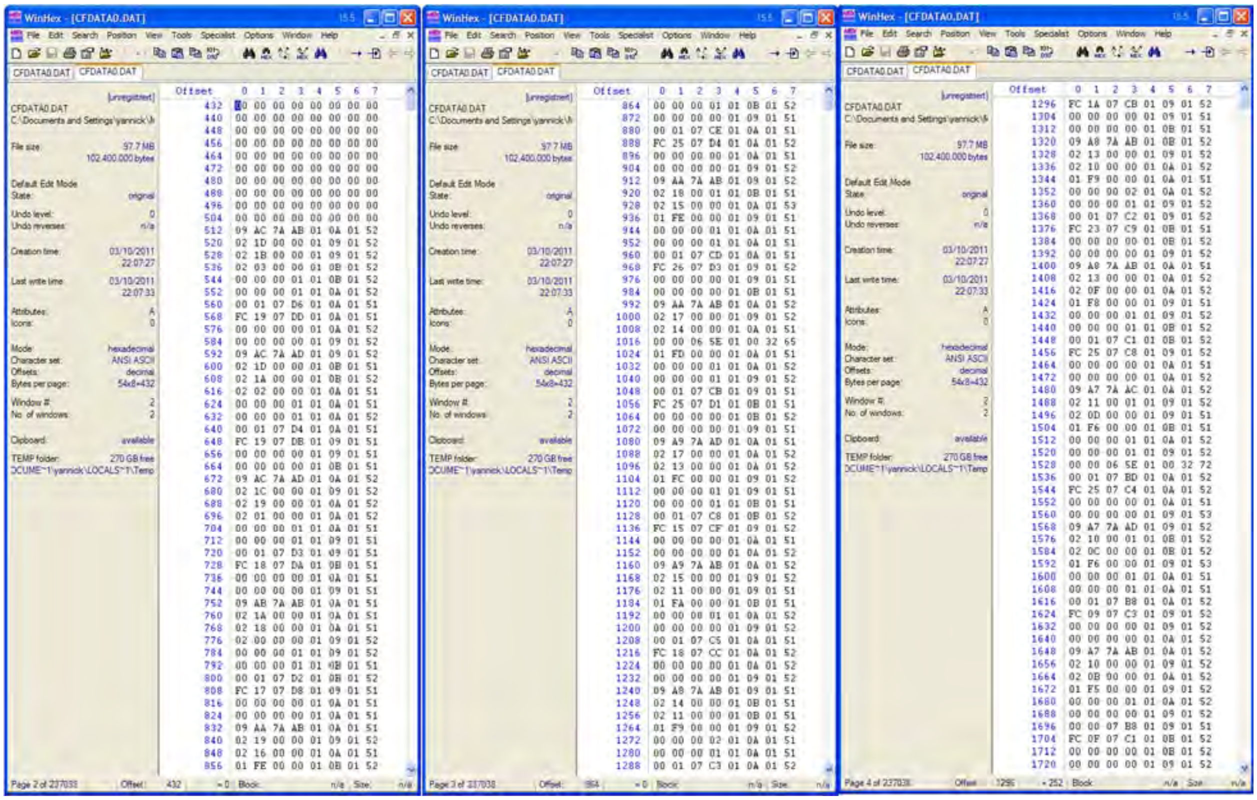


Figure 17: WinHex preview of CFDATA.DAT

At the next ms, channel 2 of LFCHIP1 is written, then channel 2 of LFCHIP2, then the second sample of HFchip1, and finally the second sample of HFChip1. Because the LF signals are digitized at 100Hz, the HF signals at 1kHz, and because we only have 8 channels per chip (so 16 LF channels total), in order to keep a regular pattern where every time 10 HF samples are collected, 1 sample from each LF channels is also collected, we assume the existence of 2 virtual channels per LF chip. The sampling pattern then looks like:

LF1_1_s1	LF2_1_s1	HF1_s1	HF2_s1
LF1_2_s1	LF2_2_s1	HF1_s2	HF2_s2
LF1_3_s1	LF2_3_s1	HF1_s3	HF2_s3
…			
LF1_8_s1	LF2_8_s1	HF1_s8	HF2_s8
LF1_9_s1	LF2_9_s1	HF1_s9	HF2_s9
LF1_10_s1	LF2_10_s1	HF1_s10	HF2_s10
LF1_1_s2	LF2_1_s2	HF1_s11	HF2_s11
…	…	…	…

Table 1: DAQ sampling pattern where LF1_1_s1 stands for LF chip1, channel1, sample 1 and each sample being a 16 bit Hex word, i.e., AE54.

Therefore, every 10 HF readings, all LF channels have been read once and thanks to the 2 extra virtual channels per LF chip, the pattern stays in synch.

Note that the first sector is always empty. This pattern is recognizable in Figure 17. At offset 512 (bytes), if we read the first two columns that consist of the samples for LF chip1, we have:

09AC
021D
021B
0203
0000
0000
0001
FC19
0000
0000
09AC
021D
021A
0202
0000
0000
0001
FC19
0000
0000

where the 9th and 10th channels marked in grey (looks like 2 other real channels are empty). Thanks to the 2 virtual channels, the 1st, 10th, 20th,… samples of the HF chips will always be matched to the samples of the first channel of LF chip 1 & 2. This will make it easy to write the code for reading the data.

The last 8 bytes of each sector:

Because the last 8 bytes of each 512 bytes long sector are reserved for a counter and time (time not logged anymore due to issues with the real time clock), only 504 bytes per sector are available for real data. since 1 line in the winHex preview is 8bytes long (4 samples at 2 bytes/sample), we can count 63 lines of data per sector and see what the 64th line looks like. Looking at Figure 17, the first sector is skipped as it is used for a header. Starting at byte 512, a new block starts. If we count 63 lines from there (or go directly to Offset 1024-8=1014, the last line of the sector is:

00 00 06 5E 01 00 32 65

0000065E is the counter (4 bytes sample) and 01003265 was meant to be the real time clock (that time is not used anymore because every time the DAQ is powered off, the real time clock looses track of real time. It is an issue that did not make sense and that we did not have time to resolve).

The counter repeats until connection to the sparkfun logger is detected at which time, the counter will start incrementing by 1/sector. Repeating the counter and then incrementing it by 1 once connection to the sparkfun is made allows to synchronize the DAQ data with the sparkfun data. Since the sparkfun will always take some time to start writing data, by incrementing the counter as soon as the sparkfun is logging data allows us to know how many DAQ blocks to discard.

Note that the counter always starts at a random number. This is done so that we'll know where data collection stopped. Indeed, when the Flash card is reformatted, data do not disappear. Just the file pointer is reset to the beginning of the file and new data just overwrite previously recorded data.

Say you had recorded data for 1 hour and then you reformat and record data for 10 minutes. When reading the CFDATA.DAT file, at the end of the 10 minutes, you start seeing the old data and reading will continue. By starting the counter at a random number, whether the counter is incrementing by 1 or

not, at the end of the data record, the counter will jump to some completely different number corresponding to the counter of the previous data record. By doing this, we therefore know where to stop.

Going back to our example file of Figure 17, the next counter is found at Offset 1024+512-8=1528 and reads:

00 00 06 5E

If we were to move further down the file, we would see the counter jumping to 00 00 06 5F. This would indicate the point where the sparkfun started logging data and everything before that point would be thrown out.

Swap file size and maximum record length:

As mentioned earlier, the data are written to a swap file meaning that we have file of fixed size receiving data. This file can be set to any size. The smaller, the better since it limits the amount of disk space to store the data but also, the smaller the swap file, the faster it will be to read the file.

A sector is 512 bytes representing 63 lines of data (2 HF readings and 2 LF reading per line). So each sector represents 0.063 seconds. Therefore, total record length available as a function of swap file size is:

Swap file size	Maximum record length
10Mb	20 minutes
100 Mb	3 hours 24 minutes
200 Mb	6 hours 45 minutes
400Mb	13hrs 36 minutes

The size of the swap file is set by programming the PIC (see procedure below)

Operating the DAQ:

Operating the DAQ is very straight forward. There is only a couple things to be aware of:

1. The absolute maximum rating f power supply cannot be larger than +7V and less than -0.3V.
2. When the DAQ is turned on, the Green LED will light up.
3. The flash card can either be inserted before powering the DAQ or after. In either case, the RED LED should light up as it indicates that data are being written to the Flash card.
4. Powering off the DAQ and on a gain while the flash card is inserted will just result in a new CFDATAx.DAT file being created where ‘x’ is an incrementing number.
5. Remember that A8 and A9 (LF chip1 channel 8 and LF chip 2 channel 1) are hardwired to the switch signal and a voltage reference (2.5V/2).
6. Remember that some channels have voltage dividers.
7. DO1 is the digital switch generated by the DAQ itself. It is used to control the solenoid switch of the pitot card. It goes high (2.5V) for 3 sec and low (0V) for 57 seconds. That switch is digitized by A8.
8. The flash card should always slide in seamlessly. If not, check that there are no bent pins and that the rails guiding the flash card in are not hanging.
9. The flash card needs to be formatted as FAT (not FAT16).

Programming of the PIC:

1. For new computer that never had the drivers installed.

- Open SIlabs folders and run set up.
- Drivers will be installed but when plugging DAQ for first time with USB, it will ask to point to drivers. choose C:/SIlabs/MCU/CP.....

2. Open zip file of TI folder and run to install.
3. The .bat file has parameters for communicating with the daq

4. Uploading new code from ken (.hex file). Ken generated hex files that each contains variation for the ADC input channels setup. The two ADC chips used for digitizing of the HF data can be run in either differential or non-differential. The codes provided by Ken offer the following possibilitites:
   - Chip1 diff ; Chip2 diff
   - Chip1 diff ; Chip2 single-ended
   - Chip1 single-ended ; Chip2 diff
   - Chip1 single-ended ; Chip2 single-ended

5. Choose the hex program of your choice from one of the folders and copy and paste in main folder (parent folder) changing the name back to DAQ.hex
6. In read me file take note of what this code is.
7. Plug the DAQ to computer with USB (assuming the drivers from SIlabs and TI were installed)
8. In device manager note the com-port that is used.
9. In .bat file RMB and edit, then set **/p** to port number so e.g. p5 for com5
10. Double click the .bat file to execute it. The program will launch.
11. Do cancel on first message
12. Hold the white button on DAQ next to U25 (big black chip, not the dump button). Daq needs to be powered of course
13. While holding button hit run on program on computer. it will upload new .hex code.

4.2 General Hot wire anemometry principles.

Hot wire anemometry is based on heat transfer from a heated wire element placed in the fluid flow. The heat transfer from a heated wire placed in fluid flow depends on:

1- the properties of the ambient fluid (density, viscosity, thermal conductivity, specific heat) and,
2- the parameters of the flow (U, temperature, pressure).

Any change of the fluid conditions which affect the heat transfer can be measured. A standard hot-wire/cold-wire probe has a flat frequency response from 0 to 20-50 kHz and therefore any changes in the fluid flow conditions that affect the heat transfer from the heated element will be detected virtually instantaneously by a constant temperature HWA system.

There are two main modes of operating a hot wire probe:

1- The constant temperature mode (CT) for velocity measurements in which the probe resistance (and thereby temperature) is kept constant by varying the current flowing through the probe.
2- The constant-current mode (CC) in which the probe's temperature varies.

The sensitivities of the wire voltage Ew is related to temperature and velocity changes by:

$$e_w = S_U.U + S_\theta.\theta$$

where S_U and S_θ are the sensitivities to velocity and temperature respectively, i.e., S_U=dE_w/dU and S_θ=dE_w/d_θ. Typical values for the sensitivity curves are shown in the figure below for a 2mm long 5micron diameter tungsten probe operated in the constant current mode:

2.1 HEAT TRANSFER 31

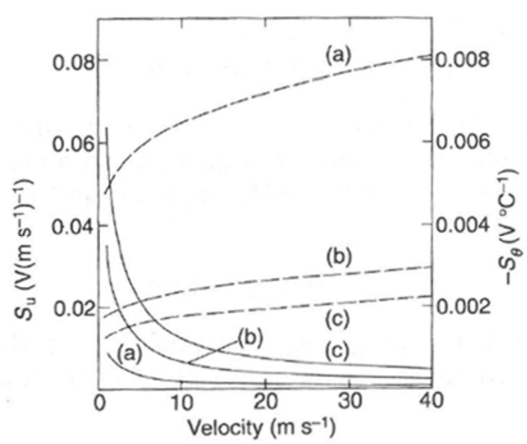


Fig. 2.3. The variation in (---) the velocity and (—) the temperature sensitivity with velocity and for temperature differences $T_w - T_a$ of: (a) 10 °C, (b) 100 °C and (c) 250 °C.

Figure 18: From Bruun. Sensitivity of a hot wire heat transfer to temperature and velocity (note: There is an error in this figure. The labels a), and c), should be reversed)

For a given velocity U, the sensitivities S_U and S_θ vary inversely with Tw-Ta, with the value of Su increasing and the value of S_θ decreasing with increasing values of Tw-Ta. A high overheat ratio (Tw/Tcold) is recommended for the measurement of velocity fluctuations.

For temperature measurements, a hot wire is often operated in Constant Current mode (CC) as a resistance thermometer using a very low overheat ratio. When the probe is placed in a non-isothermal flow, both Ra and Rw will vary with time. The fluctuating voltage e_w from the resistance wire is related to the temperature and velocity fluctuations by

$$e_w = S_{\theta\_cc}.\theta + S_{u\_cc}.U$$

where S_{θ_cc} and S_{U_cc} are the sensitivities of the constant current hot-wire probe to temperature and velocity (different than S_U and S_θ). To avoid contamination of the temperature signal by the velocity fluctuations, the ratio S_{U_CC}/S_{θ_CC} is minimized by operating the resistance wire with as low of a current as possible (retaining a sufficiently large signal-to-noise ratio of the CC anemometer system).

Probe:

The dimensions of the hot wire sensor should not be much larger than the Kolmogorov length scale (the smallest eddies). A typical sensor is about 5 micron in diameter and 1.25 mm long which provides a very small sampling volume. Hot wire anemometers can have very low noise levels.

To obtain good frequency response, most HW sensors have a diameter of 5microns or less.

A single sensor hotwire probe consists of a short length of a fine diameter wire attached to two prongs which are usually made of stainless steel or nickel. The active part of the wire element may extend to the prongs or it may be restricted to a central part by using plated wire ends near the prongs.

To maximize signal-to-noise ratio, one should:

i) Operate the wire at a high overheat ratio
ii) Use a wire material with a high temperature coefficient of resistance
iii) Use a thin wire to minimize its thermal capacity.

Probe breakage will happen due to burn out which will occur if the overheat ratio is accidently set too high. Also, tungsten oxidizes at ~350C so tungsten probes are typically heated to less than 250C.

Note: Limitations. At very low velocities, natural convection from the hot-wire probe becomes important. Its effect depends on the value of the Grashof number, Gr, and Collis and Williams 1959 concluded from their experiments in air with hot-wire probes with large values of the length to diameter aspect ratio l/d that the buoyancy effect on the fluids turbulence properties can be neglected when:

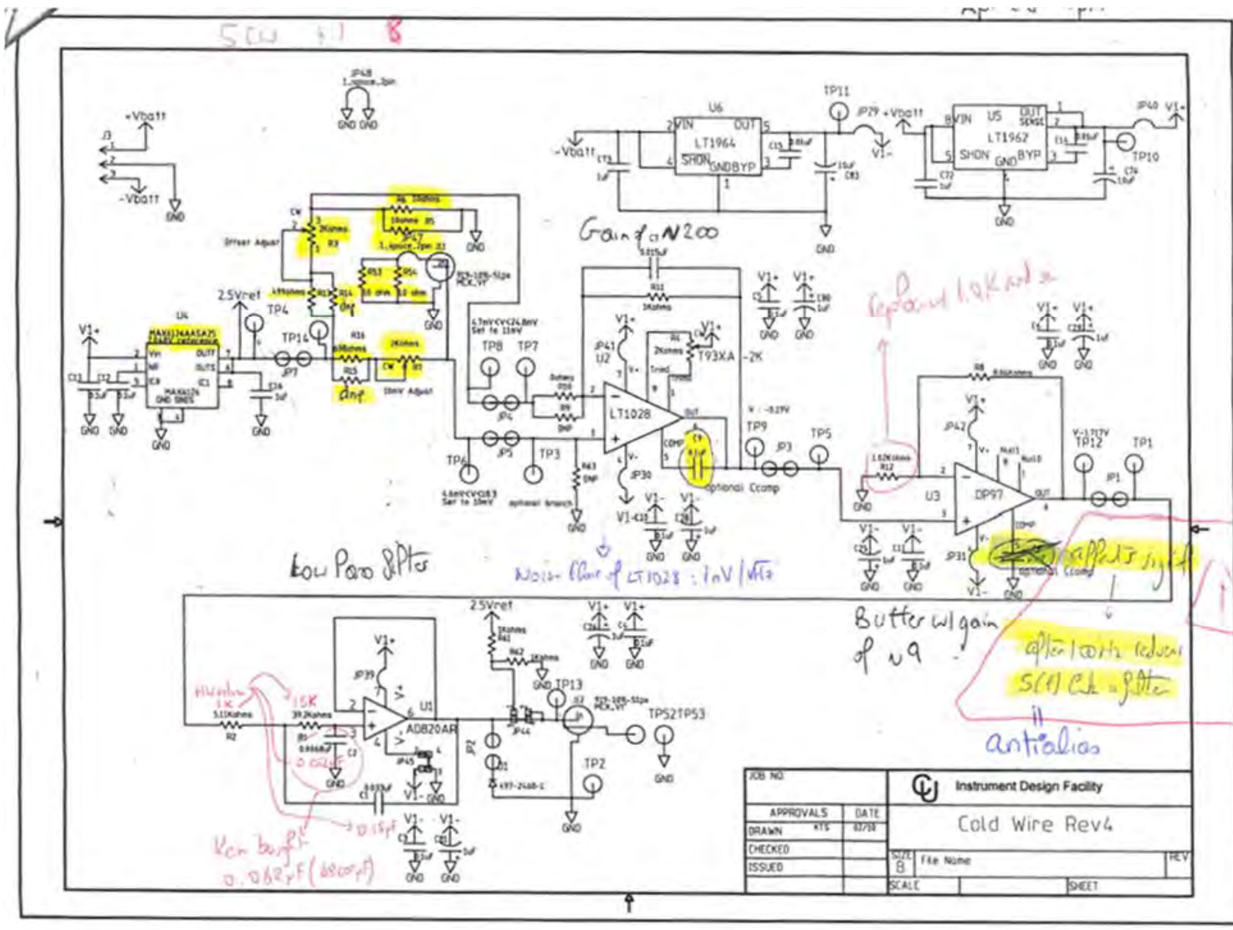
$$Re > Gr^{1/3}$$

with:

$$Re = \frac{\rho U d}{\mu}$$

$$Gr = \frac{\rho U d}{\mu}$$

4.3 **Cold Wire (Constant current thermometer)**



The cold-wire circuit consists of a series of 5 stages:

1- Stage 1: A 2.5V voltage reference feeding the top node of a Wheatstone bridge effectively setting a constant current in both branches of the bridge.
2- Stage 2: The Wheatstone bridge used to measure the unknown resistance of the probe.
3- Stage 3: A low-noise differential operational amplifier measuring the voltage across both middle nodes of the bridge.
4- Stage 4: A buffer and gain stage used to add more gain since the amount of gain that can be set with the opamp of the 3rd stage is not enough to set the targeted total gain of the circuit.
5- Stage 5: A sallen-key antialias filter that cuts off the signal above 500Hz so as to minimize the effect of spectral folding/aliasing.

Note about optimal Gain setting:

The total gain of the circuit is chosen so that the noise floor of the first stage opamp is above the level of the digitizer's bit noise. The detector being extremely sensitive, the only limitation is the noise level of the first stage opamp and the LT1028 is the highest precision opamp on the market.

The peak-to-peak resolution of an AD7738 operated at a sampling rate of 1kHz and with an input range of 0-2.5V is 16.8 bits. This number is the number of flicker-free bits and therefore the number of bits that can be trusted. This corresponds to a resolution of:

$$\Delta V_{ADC\_1kHz} = \frac{2.5}{2^{16.8}} = 21.9\ \mu V$$

The variance of Gaussian noise with an amplitude ΔV_{ADC_1kHz} is :

$$\sigma^2 = \frac{\Delta V_{ADC_{1kHz}}^2}{12} = N \times Bandwidth$$

Therefore the level of the smallest resolvable fluctuations is:

$$N_{DAQ} = 8e\text{-}14\ V^2/Hz$$

Assuming a 16 bit resolution this would be:

$$N_{DAQ} = (2.5/2^{16})^2/(12x500) = 2.4\ e\text{-}13\ V^2/Hz = 480\ nV/Hz^{1/2}.$$

Figure 19 shows that the effective resolution achieved is more like 16 bits since the noise level seen in a spectrum of constant signal fed to the ADC (1.5V battery) has a noise floor at ~2.4e-13 V^2/Hz (indicated by bottom red line).

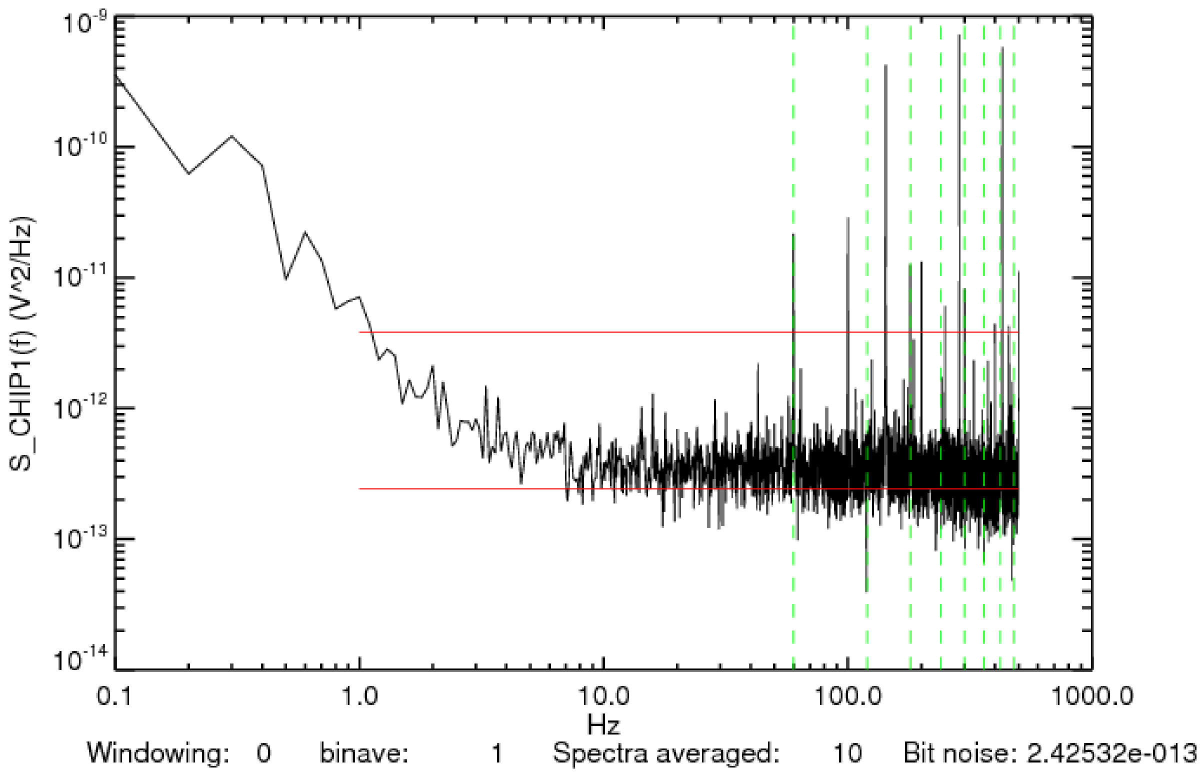


Figure 19: Spectrum of HF channel when fed with 1.5V.

Because the noise floor of the LT1028 is 1nV/$Hz^{1/2}$, and that of the digitizer is 480nV/$Hz^{1/2}$, the minimum gain needed for the CW signal to stay above the digitizer's bit noise is ~500. This gain is set in two stages since the LT1028 alone can only add so much gain. The current design sets a gain of approximately 1800 which might be overkill since reducing that gain to 900 could gives twice as large of a dynamic range

while maintaining the same temperature resolution. At the last stage of the circuit, the signal goes through a Sallen-key anti-alias filter with a cutoff frequency of 750 Hz.

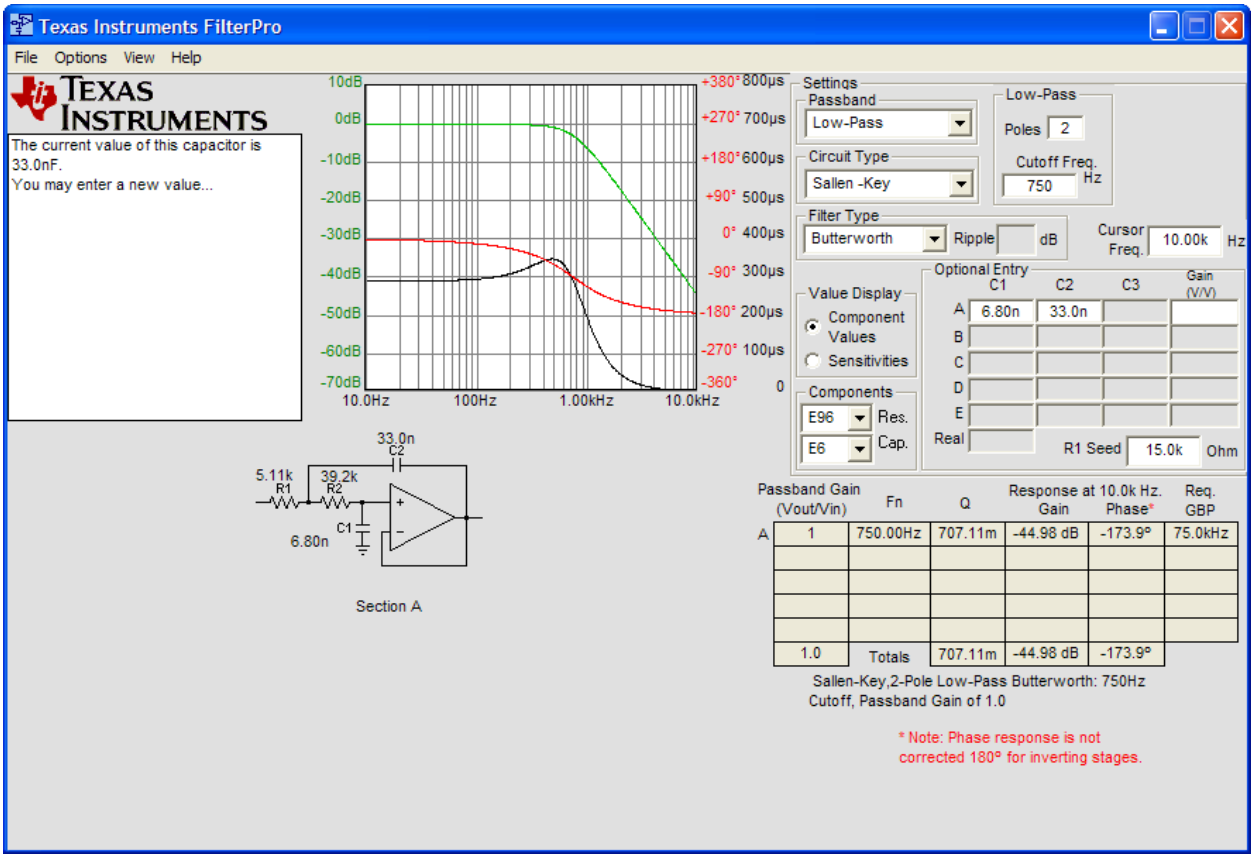


Figure 20: CW anti-alias filter

Temperature sensitivity/resolution of the CW circuit:

The resolution of the temperature fluctuations that the CW circuit can resolve is only as good as the noise floor of the electronics since the detector itself is extremely sensitive. Tungsten having a temperature coefficient of

TempCo_Tungsten = 0.0046 ohms/C,

and assuming a current of 2 mA (which is set when setting 10mV across the 5Ω probe), the sensitivity of the detector in Volts therefore is:

$$\Delta V_{Detector} = 9.2\ \mu V/C.$$

The LT1028 peak to peak noise in the 0.1-10Hz frequency range is 35 nV (see data sheet). Therefore the resolution of CW temperature measurements is:

$$\Delta C_{CW} = \frac{35\ nV}{9.2\ \mu V/C} = 0.0038\ C$$

This resolution is more or less confirmed by real atmospheric measurements collected in a very quiet region of the residual layer and which spectrum is shown below:

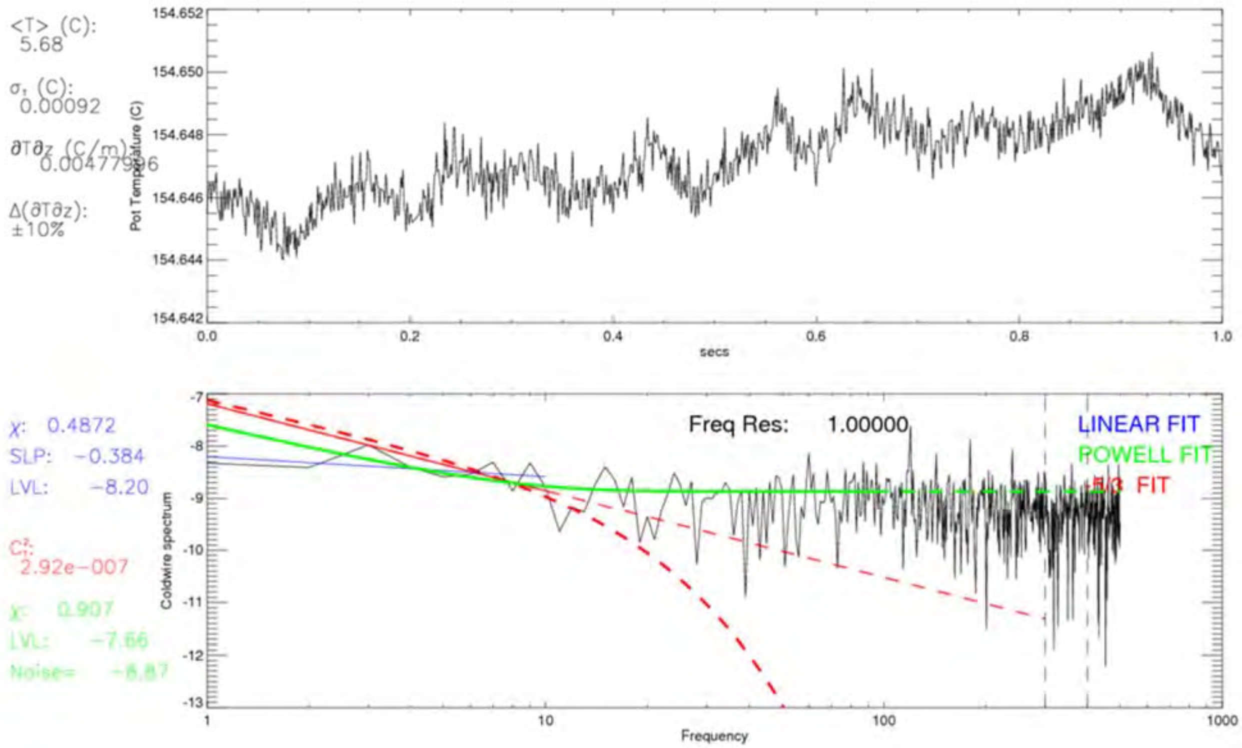


Figure 21: CW resolution

The time series of Figure 21 seems to indicate a resolution of roughly 0.002C since the higher frequency fluctuation observed in the time series, which have characteristic amplitudes of 0.0005C are obviously a consequence of the thermal noise properties of the LT1028 (the spectrum is almost entirely noise).

To avoid drift effects on the opamps due to changes of the power supply voltage, two voltage regulators are used to create regulated +5V and -5V. Potential effects of temperature on the output voltage of the 2.5V voltage reference are nulled since the output of the reference is split into both branches of the bridge, thus affecting both branhes equally. The measured voltage across the middle nodes therefore remains unaffected by potentials drifts of the reference voltage.

The trimming potentiometer of the bottom branch (the one connected to the probe) is used to set the small current flowing through the probe. This is done by adjusting the pot until TP6 reads 10mV (so ~ 2 mA assuming the 'cold' resistance of the probe of ~5 ohms). The top branch is used to set the offset voltage and set the operating point of the CW. Setting the operating point means setting the output voltage of the CW within the 0-2.5V range at a voltage that leaves enough room for the signal not to be clipped when temperature either rises (i.e. such as when you profile upward through an inversion) or lowers (temperature drops throughout the night).

To get an idea of where the operating point should be set one needs to refer to the transfer function of the first stage opamp:

$$Vout = Gain\,Vref\,\frac{Rp}{Rp + R3} - Gain\,Vref\,\frac{R1//Rf}{R2 + R1//Rf}$$

with:

$$Gain = 1 + \frac{Rf}{R1//R2}$$

and

- Rf is the resistor of the LT1028 feedback loop (R11 in schematic),
- R1 is the hardwired 5ohm resistor of the top branch (R2 in **Error! Reference source not found.**),
- R2 is the trim pot in series with the 499 ohms resistor of the top branch,
- R3 the trim pot in series with the 698 ohms resistor of the bottom branch,
- And Rp is the probe's resistance.

Since:

$$R_P = R_{P\_cold\_25C}[1 + \alpha(T - T0)] \text{ with } \alpha = 0.0045\ \Omega/C$$

the output voltage expressed in terms of temperature is:

$$V_O = Gain \times Vref\left[\alpha\frac{R_{Pcold}}{R3}\left(1 - \frac{R_{Pcold}}{R3}\right)\Delta T + \frac{R_{Pcold}}{R3}\left(1 - \frac{R_{Pcold}}{R3}\right) - \frac{R1//Rf}{R1//Rf + R2}\right]$$

With the values of the schematic the gain is:

$$Gain = 1 + \frac{1000}{R1.R2/(R1 + R2)} \sim 1 + \frac{1000}{R1} = 1 + \frac{1000}{5} = 201$$

Note that the offset is adjusted with R2. However R2 is also affecting the gain so the gain should change. The maximum and minimum values for the gain are:

$$1 + \frac{1000}{5 \times 2499/(5 + 2499)} < Gain < 1 + \frac{1000}{5 \times 499/(5 + 499)}$$

$$201.4 < Gain < 203.0$$

Therefore at 25C, using the minimum value for R2 (pot all the way CCW), Vo would be:

Vo = -2.9995 V

And with R2 set to the max (R2=2000+499), Vo would be:

Vo = +1.456V.

We can calculate some values as a function of temperature and the 'Low' and 'High' setting of the offset pot (Low is for R2=499+0) and accounting for the gain of 9 of the next stage:

T	V_{CW} = $Vo_{\_Low}$ x 9	V_{CW} = $Vo_{\_High}$ x 9
-10C	-29.4 V	6.27 V
0C	-28.6 V	7.08 V
10C	-27.8 V	7.90 V
20C	-27.0 V	8.71 V
25C	-26.6 V	9.12 V
30C	-26.2 V	9.52 V
40C	-25.0 V	10.34 V

With the 2k pot in the offset branch of the bridge, we can see that no matter the ambient temperature, we can easily set the output voltage within the 0-2.5V range and the dynamic range of 2.5V represents roughly a temperature dynamic range of 30C.

Then it is a question of setting the operating point so that there is enough room above and below to allow for temperature increases and decreases on the basis that the output voltage will vary by:

$$\frac{\partial V}{\partial T} = 0.083\ \mathrm{V/C} \sim 1\ V/10C$$

4.4 Hot wire (constant voltage mode)

In this mode of operations the wire is kept at a high temperature to maximize the sensitivity of the wire resistance to airflow (self generated heat advected away by wind) rather than ambient temperature (i.e. effect of air temperature on wire are minimal compared to the very hot temperature maintained by the wire). Indeed, at high overheat ratios, it is well known that the hot wire is primarily sensitive to fluctuations in mass flux, no matter whether it is operated in constant-current or constant temperature mode.

To keep the constant temperature, a constant voltage is applied to the terminal of the probe and a differential amplifier is used to obtain the rapid variation in the heating current that compensates for the effect of changes in the flow velocity the probe's wire resistance. In short, the high temperature keeps the wire from being sensitive to temperature changes, and changes in temperature by removal of heat from advection are instantaneously compensated by adjusting the current flowing through the probe.

The basic constant-voltage anemometer circuit is similar to an inverting amplifier circuit (see Figure 22). The difference lies in the feedback loop where the single resistor has been replaced with a T-resistor network. The voltage at the center node of the T-resistor network is constant, independent of the value of the wire resistance. Therefore a change in the wire resistance due to a variation of convective conditions results in a change in the wire current. Fluctuations in the output voltage of the circuit are proportional to these changes in the wire current, with the proportionality constant being the feedback-loop resistor R2. Modern amplifiers have a very fast response and in the CT mode the sensor can be maintained at a constant temperature except for very high frequency fluctuations.

An increase in flow velocity past the sensor cools the wire, decreases the wire resistance, and tends to cause a corresponding decrease in the wire voltage (Ew). Since the input voltage to the circuit is constant, the decrease in the wire voltage causes a decrease in the current I_1. A decrease in this current translates to an increase in the voltage at the inverting terminal of the op-amp which in turns increases the output voltage of the anemometer.

The increased output voltage cuases an increase in the feedback current I2. Most of the feedback passes through the wire resistor since R1 is typically much larger than Rw. The increased wire current leads to an increase in the wire voltage tending to maintain it at the original value.

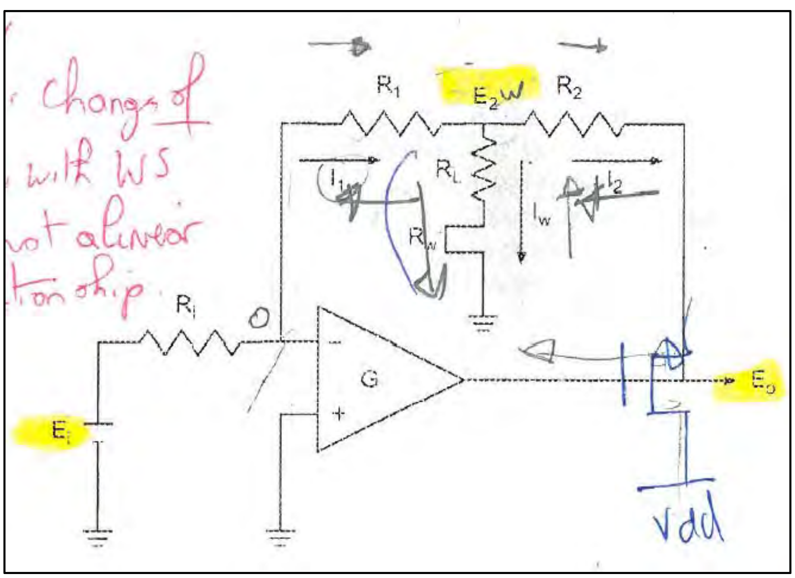


Figure 22: Constant voltage Anemometer (CVA)

The total hot-wire probe resistance, R_W+R_L is the center grounded element of the T-resistor network (where R_L is the constant lead resistance of the probe cable). The input voltage Ei to the circuit is a constant value provided by a low noise voltage supply. The measured output voltage of the circuit is denoted E_O.

Since the positive input terminal of the opamp is grounded, $E_-=E_+=0V$ and an application of the Kirchoff's current law to the inverting terminal of the opamp gives:

$$E_W= -R_1/R_i\ E_i.$$

Because E_W is constant, independent of the wire resistance, changes in the wire resistance as a result of convective changes of the wire temperature result in wire current fluctuations. Applying the Kirchoff's law to the center node of the T resistor network gives:

$$\frac{E_w}{R_w + R_L} + \frac{E_w}{R_1} + \frac{E_w - E_O}{R_2} = 0$$

And solving for the wire resistance gives:

$$R_w + R_L = \frac{R_2}{(E_o/E_w) - (R_1 + R_2)/R_1}$$

The HW circuit is equivalent to an inverting amplifier i.e.:

$$Vo= -V_-\ A$$

with A=A(f) the gain of the opamp (infinite for a perfect opamp). Applying the theorem of decomposition, the output voltage of the circuit E_0 is the result of the contribution to V- of the circuit when the output is grounded plus when the input is grounded:

$$\text{Eo grounded: } V_- = E_i \frac{R1+Rw//R2}{Ri+R1+Rw//R2}$$

$$\text{Ei grounded: } V_- = \frac{V_o\, R_w}{R_2+R_w}\left[\frac{R_i}{R_i+R_1+R_2//R_w}\right] = BV_0$$

Therefore:

$$V_o = -E_i\left[\frac{R1 + Rw//R3}{Ri + R1 + Rw//R2}\right] A - A\ B\ V_0$$

$$\boxed{V_o = -E_i\ \frac{1}{B}\ \frac{R1+Rw//R2}{[Ri+R1+Rw//R2]}\ \frac{AB}{1+AB}}$$

which is solely a function of the wire resistance (changes with windspeed), AB/(1+AB)~1 for a perfect opamp, and where 1/B is the gain of the circuit:

$$Gain = \frac{1}{B} = \frac{(R2+Rw)(Ri+R1+R2//Rw)}{Rw+Ri} = \left(1+\frac{R2}{Rw}\right)\left(1+\frac{R1+R2//Rw}{Ri}\right).$$

Complete circuit:

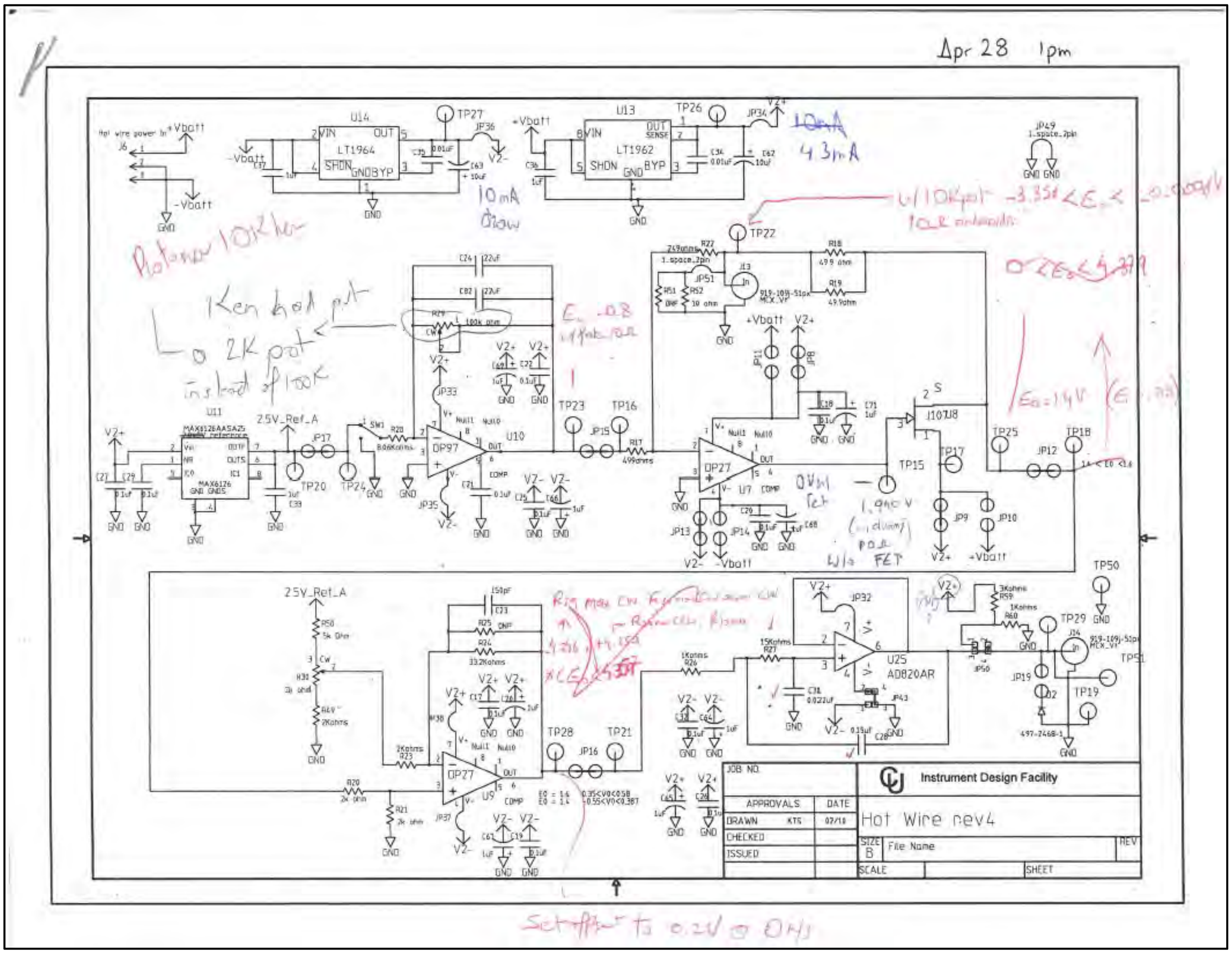


Figure 23: Hot wire circuit

Circuit Stages:

The hotwire circuit uses +5V and -5V regulators to provide the necessary voltages to the +Vs and –Vs terminal of the opamps. At the front of the circuit, a 2.5V voltage regulator feeds the input of an inverting amplifier which gain is adjustable through the use of the feedback100k trimming potentiometer (R29). Adjusting that pot allows setting the correct voltage Ei that feeds directly into the second stage hot-wire circuit:

$$E_i = -V_{ref}\frac{R29}{R26}$$

Since the pot is a 100k, Ei can be set anywhere from 0 to -3.1V.

The input of the inverting amplifier is also equipped with a switch that allows Ei to ramp up slowly to its operating point. This prevents burn outs of the HW probe which is very susceptible to the brief current surges associated with the system turning on and off. Note that with the extra protection provided by the switch, the HW circuit should never be turned on or off while a probe is connected (probe will burn out). The first step consist of turning on the circuit without a probe connected, make sure that the switch is turned off (flipped to the right), connect the probe, and then flip the switch.

The next stage of the circuit is gain+offset circuit that allows setting the output voltage of the hw stage within the 0-2.5V input range of the digitizer. That offset is typically set to 0.2V in 0 m/s wind. The transfer function of the offset stage is:

$$V_{OUT} = Gain \times Vin - Gain \times Q \times Vref$$

where the Gain is:

$$Gain = 1 + \frac{R24}{R23 + Rpot}$$

with

$$Rpot = \frac{R_H . R_L}{R_H + R_L}$$

and

$$Q = \frac{R_L \times R24}{(R24 + R23)(R50 + R30 + R49) + R_L\, R_H}$$

that is, for the pot set Low (bottom branch =2k) and high (bottom branch =2k+2k):

$$8.86 < Gain < 10.33$$

and:

$$0.201 < Q < 0.394.$$

The hotwire circuit is similar to the one found in Spina et al 1998 to the exception that a JFET is used at the output of the circuit so that the output of the opamp controls the gate and determines how much current to feed to the feedback loop. The current needed was indeed to high for the opamp to provide this current itself and therefore the output of the +5V voltage regulator is used instead.

Note that the 25 ohms R2 feedback resistor consist of two 50 ohms resistors in parallel to split the current going through each resistor in half thus allowing to stay within 1/8 W limit of each resistor. We estimate the maximum current to flow through the feedback loop to be around 100 mA which, considering a 20 ohms resistors, this corresponds to a power of :

$$P=R\, I^2= 20*0.1^2=0.2W.$$

The resistors used have a power rating of 1.4W for the 1206 whereas 0603 resistors have a rating of 1/16 W. If we were to use a sinlge 20 ohms resistors, we would be close to its threshold for the 1206 but above it for a 0603 resistor. By splitting the between two 40 ohms resistors in parallel, we effectively get 50 mA per resistor corresponding to a power of $40*0.05^2= 0.1$. This is still below the 0.25 W of a 1206 but above the 0.065 W of a 1/16 W resistor. Therefore, 1206 resistors should be used.

Lastly, the last stage is an anti-alias filter with a cutoff frequency of 750Hz:

Note that the resistors used here are smaller than in the CW because the CW has a huge gain that boosted the noise floor to a level that is much higher than the thermal noise induced by the resistors of the sallen-key. However in the case of the HW, because the noise floor is lower (not as much gain), we need to use smaller resistors so as to minimize the amount of noise generated by the resistors. The settings of the low-pass filter are shown below:

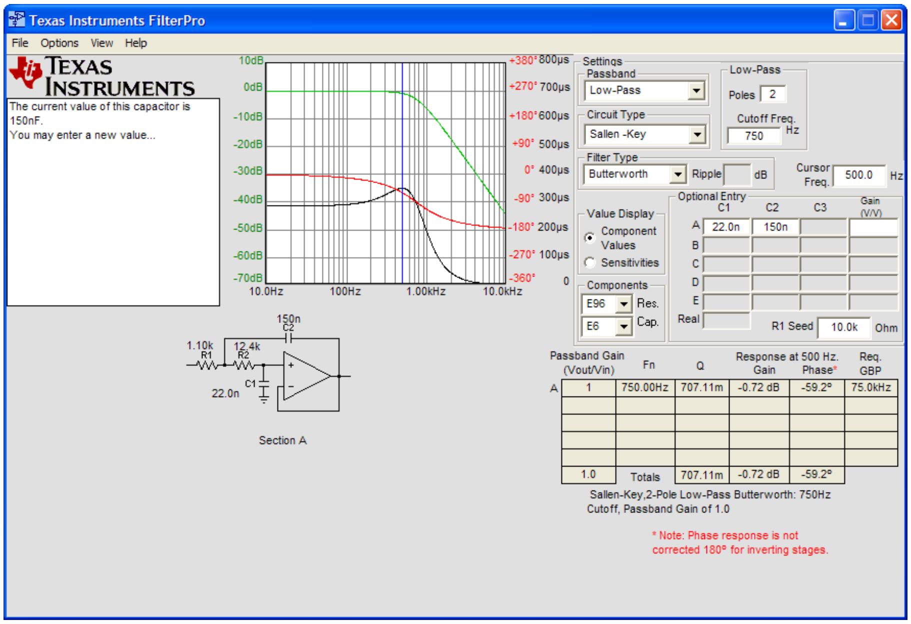


Figure 24: HW Sallen-Key antialias filter

Because the values 1.10k and 12.4k are not easy to find, we instead use 1k and 15k.

The values of the resistors at the first stage opamp are chosen so that the dominant source of noise is that of the 2.5V reference instead of the noise generated by the resistors.

Calculation the overheat ratio:

For each probe, we need to calculate the input voltage Ei to set in order for the probe to operate at a specific overheat ratio (Typically 1.8).

The overheat ratio is:

$$\tau = \frac{Rw\_hot}{Rw\_cold}$$

Because we cannot make a measurement of Rw_hot since it is the resistance of the probe as the HW card is powered, Rw_hot is calculated based on the the measurement of voltages at various points of the the circuit.

Rcold is also difficult to measure since Rcold is the resistance of the wire itself and not of the whole probe which has the prings, wires inside the probe, the MCX connector and the cables leading to the HW card. Therefore Rw_cold is also calculated. It is done by letting just enough current flowing through the probe so that the probe circuit still works but the probe is still cold. Then use our measurements at various points of the circuit and our measurement of the resistance of the MCX cable to deduce the probe’s resistance.

The resistance of the coax cable is measured with the electronic shop ohmmeter using a 4-wire measurement (with 2 wires, to cancel out the resistance of the ohmmeter leads). The resistance of both the outer and inner conductors are measured and added and gives Rc (R_cable).

In the sample spreadsheet of Figure 25 the resistance of the cable is shown as 0.607 ohms. The internal resistance of the probe was provided by Auspex since they could measure the resistance between prong tip to connector before installing the wire (would be too difficult the make that measurement with the wire installed because of the fragility of the wire). The internal resistance is 0.85 ohms and thus a total Lead resistance (RL) of 1.457 ohms. Not accounting for that resistance might cause problems when calculating the overheat ratio.

Now that we have RL, we calculate RW+RL using the voltages Ei and Eo. We do that with the probe run cold (minimal current flowing through probe) and wheh probe is hot to calculate Rhot.

$$\boldsymbol{Rw = \frac{Ew}{Iw}}$$

where Ew is deduced from measurements of Ei (voltage that we set at the input of the circuit):

$$\boldsymbol{Ew = -\frac{R1}{Ri} Ei}$$

Iw is calculated starting with the kirchoff law at the middle node of the T resistor network:

$$\frac{Ew}{R1} + \frac{Ew}{Rw + RL} + \frac{Ew - Eo}{R2} = 0$$

which can be rearranged and expressed as:

$$\frac{R2 + R1}{R1} Ew + R2\, Iw = Eo$$

Giving:

$$\boldsymbol{Iw = \frac{1}{R2}\left[Eo - \left(\frac{R1 + R2}{R1}\right) Ew\right]}$$

Therfore, Rw is:

$$Rw + RL = \frac{E_w\, R_2}{E_0 - E_w\left(\frac{R1 + R2}{R1}\right)}$$

To calculate Rcold we set Ei to 0V so that no current flows and we monitor Eo. As soon as the voltage becomes non-negligible, we use that value of Eo for the calculation of Rw_cold.

To calculate Rhot we use the same procedure starting from Ei=0V and increasing Ei incrementally checking the overheat Rhot/Rcold everytime making sure that it does not jump to values higher than 1.8-1.9. Higher than that and the wire could burn. The higher the overheat the more sensitivity to windspeed you get (lower detector noise floor).

$$\boxed{\tau = \frac{R\_hot}{R\_cold}}$$

Make sure to use the correct RL since both cables are of different length and therefore resistance.

Use the excel spreadsheet for the calculation of the overheat and do so for every probe you intend to use with the hot wire circuit. Take notes of the Ei voltage needed to set the overheat.

	A	B	F	G	H	I	O	P	Q	R	S	T	V	W	X	Y	Z
1	**Date:**	9/27/2010															
2	**Payload:**	Final Prototype			Legend:	Set	Measured										
3																	
4																	
5	Probe Gen.	Cold Rw+RL	Ei set	Turns CCK	Eo measured	Ew	Rw+RL		Rc (Cable)	Rint (internal	RL	Rw	Tauw	R1	Ri	R2	Gain
6		It's the value calculated	Measured	Set	Measured	-Ei*R1/Ri	Calc.				cable + internal		=Rw/Rwcold				
7		in column O when cold	-0.973		1.711				0.607	0.850	1.457	=(Rw+RL)-RL		249	499	24.95	#VALUE!
8							=Ew R2/[Eo-Ew(R1+R2)/R1]										
9	**Procedure**																
10	The goal is to determine what Ei needs to be set at (for each probe)in order to the overheat ratio to the correct value (sually 1.8).																
11	Overheat=Rw_hot/Rw_cold but we can't directly measure Rw (Cold or hot). So it is calculated based on measurements of Eo, Ei, and the resistance of the leads.																
12	First , we need to calculate Rw_Cold. It is done by letting just enough current flowing through the probe so that the probe circuit still works but the probe is still cold.																
13	Once this is done, we hardwire the value of Rw_Cold and then turn the pot to change increase Ei, each time calculating Rw_hot and thus the overheat ratio (Rw_hot/Rw_Cold)																
14																	
15	The resistance of the probe written on the boxes is only used as reference to compare with what we get from the calculations.																
16	The resistance of the coax cable are done using Ken's advanced ohmmeter using a 4-wire measurement (wth 2 wires, the resistance of the ohm-meter leads affect reading).																
17	Once you have RL (resistance of the coax), you also need to account for the internal resistance of the probe. KC from Auspex Scientific says it is 0.85 ohms.																
18	We now have RL_TOT=RL_probe+RL_coax																
19	After calculating Rw+RL we substract RL to get RW for the overheat calculation.																
20	The resistance of the coax cables will vary with the packages. Therefore either you calculate the settings for each probe and each package or you only use some probes for some packages.																
21																	
22	The higher the overheat, the more sensitivity you get (lower detector noise floor). However, if you set it too high, the probe will burn/break. A setting of 1.8 is good.																
23																	
24	Use few turns to have minimal current flowing to get good estaimte of Rw+RL																
25	Probe E	Rw+RL Calc	Ei set	Turns CCK	Eo measured	Ew	Rw+RL	Rw+Rint meas	(Rw+RL)-Rc		RL	Rw Calc.	Tauw	R1	Ri	R2	Gain
26																	
27			-0.0007	0.00	0.0032	0.000	3.095	3.900	2.488		1.457	1.638		249	499	24.95	
28			-0.0012	0.00	0.0033	0.001	5.657	4.900	5.657		0	5.657		249	499	24.95	
29			-0.002	0.00	0.0057	0.001	5.411	5.900	5.411		0	5.411		249	499	24.95	
30		chosen cold value	**-0.0041**	0.00	**0.0116**	0.002	**5.460**	6.900	5.460		0	5.460		249	499	24.95	
31			-0.0071	0.00	0.0202	0.004	5.422	7.900	5.422		0	5.422		249	499	24.95	
32		**Cold Value of Rw+RL:**					**5.460**										
33	Do overheat ratio calculation using calculated value for R_cold (Rw+RL):																
34	Probe E	Rw+RL Cold Set	Ei set	Turns CCK	Eo measured	Ew	Rw+RL				RL	Rw	Tauw	R1	Ri	R2	Gain
35		5.460	-0.554	5.00	1.243	0.276	7.347				1.457	5.890	1.47	249	499	24.95	
36		5.460	-0.712	6.00	1.463	0.355	8.268				1.457	6.811	1.70	249	499	24.95	
37		5.460	-0.743	6.25	1.506	0.371	8.424				1.457	6.967	1.74	249	499	24.95	
38		5.460	-0.799	6.50	1.576	0.399	8.746				1.457	7.289	1.82	249	499	24.95	
39		5.460	-0.84	6.75	1.623	0.419	9.001				1.457	7.544	1.88	249	499	24.95	
40		5.460	**-0.84**	**6.75**	1.623	0.419	9.001		with error on RL estimate		1.600	7.401	**1.92**	249	499	24.95	
41																	

Figure 25: Excel spreadsheet of overheat calculations

Note about time constant at the first stage:

The hot wire probe is very sensitive and is prone to burnouts when too much current flows through it. This can happen when the batteries are turned on which can results in a voltage surge propagating through the ground line.

4.5 Thermistor Cards

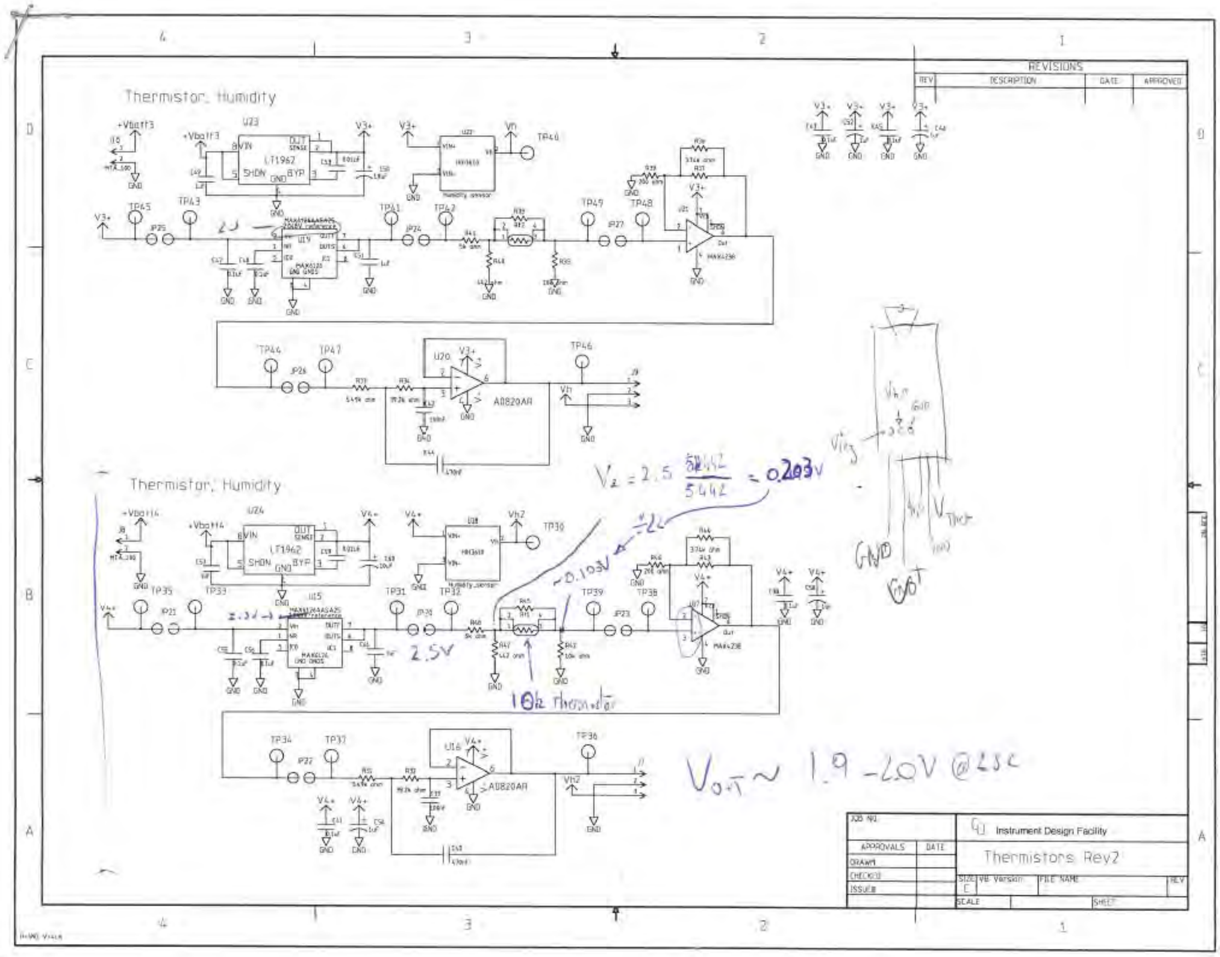


Figure 26: thermistor Schematic

A thermistor exhibits a large negative resistance change with increasing temperature that follows an exponential curve. A few parameters help describe the properties of the curves and how it changes as a function of temperature:

- The resistance of the thermistor at 25C and the temperature coefficient α are usually provided where

  $$\alpha = \frac{1}{R} \times \frac{dR}{dT}$$

  α is expressed in Ω/(Ω/C) i.e. %/C. The temperature coefficient changes with temperature, with the steepest portion of the dR/dT curve being at cold temperatures. The temperature coefficient can vary from 8%/C at the steepest portion of the curve to 1%/C at high temperatures.

- The resistance ratio is also another way to describe the curve. Ratios are provided for different temperatures and there are no standards for which temperatures to use. e.g. R_{0C}/R_{25C}, R_{25C}/R_{50C},…
- Finally the beta value is also often used to describe the curvature of the exponential curves using the following equation to model the thermistor's curve:

$$R = Ae^{(b/T)}$$

where A is a constant, b is the Beta material constant, T is the temperature in Kelvins. The value of beta will again vary with temperature, although not to the extent of what resistance ratios do.

The circuit is composed of a voltage reference feeding a resistor network that includes the thermistor followed by a gain stage and a low–pass filter. The thermistor offers a resolution of ~40mV/C and a total temperature dynamic range going from 0.4V at -20C up to 2.47C at 40C.

The transfer function of the resistor bridge is:

$$V_+ = \frac{R35}{R35 + RT + \frac{R40R41}{R40 + R41}} \times \frac{Vref}{1 + \frac{R41}{R40}}$$

and that of the gain stage is:

$$Vo = \left(1 + \frac{R36}{R39}\right) V_+$$

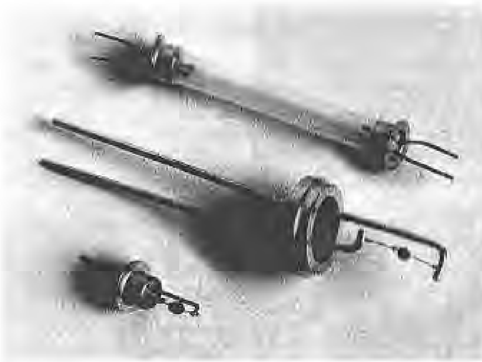
The thermistor bead used in this circuit is from Honeywell (111-103EAJ-H01 Thermistor). It is a small glass bead thermistor with axial leads. It has a ±20% tolerance, a diameter of 0.014”, a time constant in air of 0.5s, and a dissipation constant of 0.1mW/C. The following documentation provides information about the R-T curve of such a bead:

Bead Thermistors

YSI Temperature bead thermistors are elliptical bodies fabricated from metallic oxide semiconductor materials sintered on platinum-iridium lead wires. A controlled glass coating applied to these beads provides them with an effective hermetic seal against conductive, corrosive and other hostile environments. Therefore, excellent stability over long periods of time under continuous exposure to harsh ambient conditions is assured.

YSI bead thermistors are characterized by fast response times and high power sensitivities. These characteristics, as well as their small size, make bead thermistors well suited for applications involving the measurement and control of temperature and of liquid or gas flow, particularly where space is at a premium or when it is advantageous to leave the temperature of the medium virtually undisturbed by the introduction of the sensor element. Typical of such applications is the use of bead thermistors in gas chromatography and thermal conductivity gas analysis equipment, as well as in thermistor catheters and hypodermic needles for temperature and flow measurement.

YSI bead thermistors have been adapted for use in microwave power measurement applications, and are fabricated in a manner designed to improve the VSWR of the complete thermistor unit at microwave frequencies. When glass envelopes are used, they are constructed from special glass having high microwave transmission properties.



The Temperature Standard, Planetwide.™

Maximum operating and storage temperature of bead thermistors

Continuous operation: 325°C (617°F)

Intermittent operation: 550°C (1022°F)

Table 1 – Nominal Dissipation and Time Constants of Bead Thermistors (Units supported by their leads in still air at 25°)

Type of Unit	Bead Diameter (inches)	Dissipation Constant δ (Mw/°C)	Time Constant τ (seconds)	Page Number
Micro-Beads®	0.005	0.045	0.12	2
Ultra-small Beads	0.010	0.08	0.5	3
Small Beads	0.013	0.10	1.0	3
Medium Beads	0.035	0.30	5.5	4
Medium Beads	0.043	0.35	6.0	4
Microwave Beads	See specifications			6

The normal dissipation constants (δ) and time constants (τ) of bead thermistors as shown in Table 1 are measured with the specified minimum lead length between the bead and the test terminals.

All bead thermistors, by reason of their small size and the relatively high thermal conductivity of their leads, exhibit some variation in dissipation and time constants with changes in lead length. This behavior is illustrated far 0.035" and 0.043" diameter beads in Figure 1. The dissipation and time constants of smaller beads are affected to a lesser degree by their lead length in still air; however, the effect becomes more pronounced in ambients with lower thermal conductivity (e.g., vacuum).

Table 3 – 0.010" Diameter Ultra-Small and 0.013" Diameter Small Beads

YSI Part Number				Zero-Power Resistance	Temperature Coefficient	Ratio		R-T Curve (page 5)
0.010" Diameter		0.013" Diameter		Ro @ 25°C (Ω±25%)	α @ 25°C (%/°C)	Ro @ 25°C / Ro @ 50°C	Ro @ 25°C / Ro @ 125°C	
Fig. 4	Fig. 5	Fig. 4	Fig. 5					
31A7	31A36	31A45	31A46	1,000	-3.3	5.2	13.2	A
–	–	31A1[2]	31A47[2]	1,250	-3.4	5.6	14.6	B
32A172	32A173	32A174	32A175	1,500	-3.4	5.6	14.6	B
32A50	32A130	–	32A7[1]	2,000	-3.4	5.6	14.6	B
–	–	32A48[2]	32A49[2]	2,000	-3.4	5.6	14.6	B
33A77	33A78	33A79	33A80	2,500	-3.4	5.6	14.6	B
33A27	33A28	33A29	33A30	3,000	-3.4	5.6	14.6	B
–	–	34A2[2,3]	34A1[1,3]	3,500	-3.6	6.2	16.9	B2
34A18	34A19	34A20	34A21	4,000	-3.6	6.0	16.1	B
35A5	35A24	35A30	35A31	5,000	-3.6	6.0	16.1	B
38A9	38A10	38A11	38A12	7,500	-3.8	6.8	19.3	C
–	–	38C2	38C1	8,000	-3.8	6.9	19.7	C
41A5	41A14	41A22	41A23	10,000	-3.9	7.1	20.6	D
42A23	42A24	42A27	42A28	15,000	-3.9	7.1	20.6	D
42A25	42A26	42A29	42A30	20,000	-3.9	7.2	21.0	D
43A69	43A70	43A71	43A72	25,000	-3.9	7.2	21.0	D
43A6	43A20	43A2[4]	43A1[4]	30,000	-3.9	7.3	21.4	D
44A6	44A7	44A8	44A9	40,000	-4.0	7.4	21.8	D3
45A4	45A25	45A23	45A24	50,000	-4.0	7.4	21.8	D3
48A5	48A6	48A7	48A8	75,000	-4.4	9.2	30.1	F
51A22	51A59	51A30	51A32	100,000	-4.4	9.2	30.1	F
52A19	52A20	52A23	52A24	150,000	-4.4	9.4	31.1	F
52A21	52A22	52A25	52A26	200,000	-4.4	9.4	31.1	F
53A44	53A45	53A46	53A47	250,000	-4.5	9.6	32.1	G
53A3	53A4	53A5	53A6	300,000	-4.5	9.6	32.1	G
54A7	54A8	54A9	54A10	400,000	-4.6	10.3	35.8	H
55A5	55A16	55A9	55A8	500,000	-4.6	10.3	35.8	H
58A2	58A3	58A4	58A5	750,000	-4.7	10.9	39.4	Q
61A5	61A14	61A9	61A8	1 Meg	-4.7	10.9	39.4	Q
62A9	62A10	62A13	62A14	1.5 Meg	-5.0	12.3	49.6	P
62A11	62A12	62A15	62A16	2 Meg	-5.0	12.3	49.6	P
63A43	63A44	63A45	63A46	2.5 Meg	-5.0	12.3	49.6	P
63A3	63A4	63A5	63A6	3 Meg	-5.0	12.3	49.6	P
64A2	64A3	64A4	64A5	4 Meg	-5.0	12.6	51.9	J
65A14	65A15	65A16	65A17	5 Meg	-5.0	12.6	51.9	J

(1) These units are supplied with stub ends glass coated, as in Figure 6. (2) These units are supplied with 0.375" minimum leads. (3) Bead diameter 0.014"; lead diameter 0.002"; δ 0.3 Mw/°C. (4) Bead diameter 0.014".
Dimensions are nominal.

10K

100K

R(T) = R(25C) × mult.

Table 5 – Resistance vs. Temperature Multipliers for Standard Materials

Material Type		A1	A	B	B2	C	D	D3	F	G	H	Q	P	J	K	L
Temp Coeff. @ 25°C		-3.1%/°C	-3.3%/°C	-3.5%/°C	-3.7%/°C	-3.8%/°C	-3.9%/°C	-4.0°/°C	-4.4%/°C	-4.5%/°C	-4.6%/°C	-4.7%/°C	-4.9%/°C	-5.1%/°C	-5.3%/°C	-5.7%/°C
Beta in K		2769K	2938K	3108K	3359K	3385K	3445K	3672K	3891K	4125K	4111K	4143K	4354K	4545K	4747K	5022K
0°C/50°C		4.80±10%	5.28±5%	5.81±5%	6.36±5%	6.80±5%	7.04±5%	7.44±5%	9.06±5%	9.60±5%	10.30±5%	10.45±5%	11.78±5%	13.12±5%	14.73±5%	17.20±10%
25°C/125°C		N/A	N/A	N/A	16.94	18.76	19.80	22.06	29.30	32.39	35.46	38.07	46.64	56.69	67.84	95.60
°C	°F	Mult.	Mult.	Mult.	Mult.	Mult.	Mult.	Mult.	Mult.	Mult.	Mult.	Mult.	Mult	Mult.	Mult.	Mult.
-55	-67	29.37	32.12	36.59	45.25	51.32	54.92	62.37	96.37	107.00	116.80	118.40	137.00	158.00	210.60	-
-50	-58	22.21	24.30	27.54	33.55	37.47	40.10	44.97	67.01	73.88	80.70	81.60	94.18	107.40	140.10	
-45	-49	17.00	18.60	20.93	25.11	28.00	29.60	32.79	47.19	51.66	56.42	56.90	65.44	73.48	94.28	-
-40	-40	13.15	14.40	16.06	18.97	20.97	22.07	24.16	33.65	36.57	39.90	40.16	45.95	52.87	64.14	-
-35	-31	10.28	11.30	12.43	14.45	15.85	16.61	17.99	24.27	26.19	28.46	28.65	32.60	37.46	44.10	-
-30	-22	8.113	6.930	9.703	11.10	12.09	12.60	13.53	17.70	18.97	20.50	20.64	23.31	26.69	30.63	-
-25	-13	6.463	7.104	7.630	8.604	9.283	9.638	10.27	13.040	13.88	14.94	15.020	16.810	19.130	21.490	-
-20	-4	5.193	5.690	6.053	6.721	7.189	7.430	7.863	9.707	10.26	11.00	11.040	12.220	13.800	15.220	-
-15	5	4.207	4.559	4.836	5.291	5.614	5.778	6.072	7.295	7.663	6.110	8.1 80	8.972	9.957	10.880	-
-10	14	3.435	3.680	3.890	4.197	4.419	4.530	4.728	5.533	5.774	6.050	6.119	6.642	7.247	7.845	-
-5	23	2.625	2.992	3.150	3.353	3.507	3.580	3.709	4.233	4.390	4.572	4.615	4.959	5.321	5.707	-
0	32	2 340	2.450	2.568	2.698	2.801	2.850	2.932	3.265	3.364	3.460	3.510	3.733	3.942	4.187	-
5	41	1.951	2.073	2.102	2.185	2.251	2.281	2.334	2.539	2.600	2.663	2.691	2.828	2.952	3.096	-
10	50	1.637	1.680	1.731	1.781	1.821	1.839	1.870	1.990	2.027	2.060	2.078	2.157	2.227	2.308	-
15	59	1.381	1.404	1.433	1.461	1.484	1.493	1.509	1.571	1.591	1.615	1.617	1.658	1.693	1.734	-
20	68	1.172	1.180	1.194	1.206	1.215	1.219	1.224	1.249	1.258	1.270	1.267	1.284	1.297	1.312	-
25	77	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
30	86	0.8570	0.8540	0.3413	0.8344	0.8295	08265	0.8215	0.8057	0.8017	0.9010	0.7942	0.7660	0.7764	0.7656	0.7535
40	104	0.6400	0.6280	0.6040	0.5892	0.5791	0.5730	0.5633	0.5327	0.5240	0.5130	0.5105	0.4934	0.4772	0.4612	0.4368
45	113	0.5570	0.5395	0.5154	0.4987	0.4873	0.4805	0.4701	0.4370	0.4274	0.4154	0.4129	0.3944	0.3775	0.3609	0.3359
50	122	0.4860	0.4640	0.4417	0.4241	0.4118	0.4048	0.3942	0.3603	0.3505	0.3390	0.3359	0.3170	0.3004	0.2842	0.2599
55	131	0.4260	0.4024	0.3801	0.3623	0.3497	0.3427	0.3321	0.2986	0.2890	0.2790	0.2747	0.2568	0.2405	0.2251	0.2023
60	140	0.3752	0.3500	0.3283	0.3108	0.2984	0.2915	0.2811	0.2488	0.2396	0.2310	0.2259	0.2092	0.1936	0.1794	0.1584
65	149	0.3310	0.3053	0.2847	0.2677	0.2558	0.2491	0.2390	0.2083	0.1996	0.1923	0.1867	0.1713	0.1567	0.1437	0.1247
70	158	0.2939	0.2670	0.2477	0.2316	0.2202	0.2138	0.2040	0.1752	0.1670	0.1610	0.1550	0.1409	0.1275	0.1158	0.0987
75	167	0.2620	0.2355	0.2161	0.2011	0.1903	0.1843	0.1748	0.1479	0.1405	0.1354	0.1293	0.1164	0.1042	0.0938	0.0786
80	176	0.2334	0.2080	0.1893	0.1753	0.1651	0.1594	0.1504	0.1255	0.1186	0.1140	0.1064	0.0966	0.0856	0.0763	0.0629
65	185	0.2090	0.1840	0.1664	0.1533	0.1437	0.1364	0.1299	0.1070	0.1006	0.0960	0.0912	0.0806	0.0707	0.0625	0.0505
90	194	0.1877	0.1630	0.1470	0.1346	0.1255	0.1205	0.1126	0.0915	0.08572	0.0809	0.0771	0.0674	0.0586	0.0514	0.0408
95	203	0.1690	01453	0.1300	0.1185	0.1100	0.1053	0.09794	0.0787	0.07331	0.0694	0.0654	0.0567	0.0488	0.0424	0.0331
100	212	0.1527	0.1300	0.1153	0.1048	0.0966	0.0924	0.06547	0.0678	0.06294	0.0595	0.0557	0.0478	0.0408	0.0352	0.0270
105	221	-		-	0.09285	0.0853	0.0813	0.07484	0.0587	0.05424	0.0511	0.0476	0.0405	0.0342	0.0293	0.0221
110	230	-	-	-	0.08256	0.0756	0.0719	0.06573	0.0510	0.04691	0.0439	0.0408	0.0343	0.0286	0.0245	0.01 82
115	239	-	-	-	0.07362	0.0671	0.0637	0,05791	0.0445	0.04071	0.0377	0.0351	0.0292	0.0244	0.2206	0.0150
120	248	-	-	-	0.06583	0.0597	0.0566	0.05117	0.0389	0.03545	0.0325	0.0330	0.0250	0.0207	0.0174	0.0124
125	258		-	-	0.05903	0.0533	0.0504	0.04534	0.0342	0.03097	0.0282	0.0263	0.0214	0.0176	0.0147	0.0104
130	266		-	-	0.05307	0.0477	0.0450	0.04029	0.0301	0.02714	0.0246	0.0228	0.0185	0.0151	0.0125	0.0087
135	275	-	-	-	0.04784	0.0427	0.0403	0.03589	10.0266	0.02386	0.0216	0.0199	0.0159	0.0132	0.0107	0.0073
140	284	-	-	-	0.34323	0.0384	0.0362	0.03209	10.0235	0.02104	0.0190	0.0173	0.0138	0.0114	0.0092	0.0062
145	293	-		-	0.39150	0.0346	0.0326	0.02872	0.0209	0.01860	3.0167	0.0152	0.0120	0.0098	0.0079	0.0052
150	302			-	0.03555	0.0312	0.0294	0.02577	0.0186	0.01649	0.0147	0.0133	0.0104	0.0083	0.0086	0.0044

5

R

The last page of the documentation included above allows us to calculate the resistance of the thermistor for different temperatures. Column D is for a 10K thermistor. This table is for a thermistor we used to have in the early versions of the thermistor card. However, the company only sells thermistors in bulk (by the thousands) and we did not have anymore samples. Following is a table comparing the characteristics of the thermistor we used to use (from measurement specialties inc) and the current model (honeywell).

	Measurement Specialties	Honeywell
Ratio @ 0C/50C	7.04	7.04
Ratio @ 25C/125C	19.80	19.85
Temp coeff @ 25C	-3.9%	-3.9%/C
Beta 0C/50C	3445K	3442±90

One of the precautions to take is to make sure that the effect of self-heating is kept to a minimum. The effect of self heating is chosen to be 0.02C max. The dissipation constant of the thermistor being δ=0.10 mW/^{o}C, the self-heating effect is:

$$\Delta T_{SH} = 0.02^o C = \frac{P_{diss}}{\delta} = \frac{I_T^2 \times R_T \, Watts}{0.0001 \, Watts/C}$$

Therefore the maximum current that can flow through the thermistor is:

$$I_{T\_0.02C} = 4.47 \, \mu A$$

Assuming we were to only have the thermistor feeding the + terminal of the opamp with a voltage divider, the current flowing through the thermistor would be:

$$I_T = \frac{V+}{R35} = \frac{V_{ref}(R35/(R35 + RT))}{R35}$$

and to get 4.47 uA we would need an R35 of:

$$R35 = \frac{Vref}{I_T} - R_T = 549k\Omega$$

This would be way too big of a resistor and would add considerable amount of resistor noise which we want to keep below the level of the digitizer bit noise. We therefore have to reduce the input voltage of the reference with a voltage divider.

With the values chosen for the circuit, the thermistor current leading to self heating is:

$$I_T = \frac{V_{ref} \frac{R40}{R40 + R41}}{R35 + RT + (R40 * R41)/(R40 + R41)} = 9.95 \, \mu A$$

Once plugged into the selfheating calculation we get for a 10k thermistor:

$$\Delta T_{SH} = \frac{I_T^2 \times R_T \, Watts}{0.0001 \, Watts/C} = 0.01 \, C$$

Although the thermistor we now use is a little bit different, we use this table to get an estimate of the thermistor's resistance range over a large temperature dynamic range. The table gives the multiplier to use for adjusting the thermistor resistance as a function of temperature:

Temperature	Thermistor Resistance
-10C	10kΩ*4.53 = 45.3kΩ
0C	10kΩ*2.850 = 28.5kΩ
40C	10kΩ*0.5730 = 5.73kΩ
50C	10kΩ*0.4048 = 4.048kΩ

Using the values shown on the schematic for the resistor bridge, this gives a voltage range between -10C and 40C of:

Temperature	Thermistor resistor network output
-10C	0.036 V
0C	0.052 V

40C	0.12V
50C	0.14 V

For the thermistor to cover a temperature range of -10c to 40C, we can set a gain of 20 so that the output voltage ranges from 0.72V @ -10C to 2.4V at 40C. Note that the gain of the opamp (1+R37/R39) can be changed to increase the temperature range covered by the thermistor circuit.

The output of the circuit as a function of temperature is:

Temperature	Output Voltage
25C	1.96V
0C	1.03V
40C	2.47V

The last stage of the opamp is an antialias filter with a cutting frequency set at 50Hz (since the thermistor is digitized at 100Hz. This setting is not too critical since the thermistor data are not used for spectral analyses.

Supporting sensor: H2O or Temperature

The thermistor circuit also contains a pad to directly plug either a humidity sensor or a solid state calibrated temperature sensor. Because 2 thermistor cards are flown with each payload, one thermistor card is equipped with the humidity sensor and the other card is equipped with a temperature sensor.

The temperature sensor, a TMP36 sensor, is only used for calibrating the thermistor since the TMP36 has too much of a slow response to be used for calibrating the CW. The thermistor beads need an onboard sensor for calibration because their calibration coefficient drift with time and calibration made in laboratory are not usable.

The TMP36 has an output range of 0.1V to 2V with a linear response with temperature. At 50C, Vo should be 1.0V and at -25C, Vo=0.3V. This signal can therefore be directly fed into one of the channels of the DAQ which input voltage range is 0-2.5V (10mV/C). It has an absolute accuracy of ±1C (typical; ±2C max).

The humidity sensor is an HIH-4000 with an output voltage range of 0.75 to3.75V at full scale (0-100% humidity). It has a 15s response time. Because at full sacle the humidity sensor output voltage that is larger tha n2.5V, the signal goes through a voltage divider (on the DAQ) to cut the voltages by half before digitizing.

4.6 **Pitot Card**

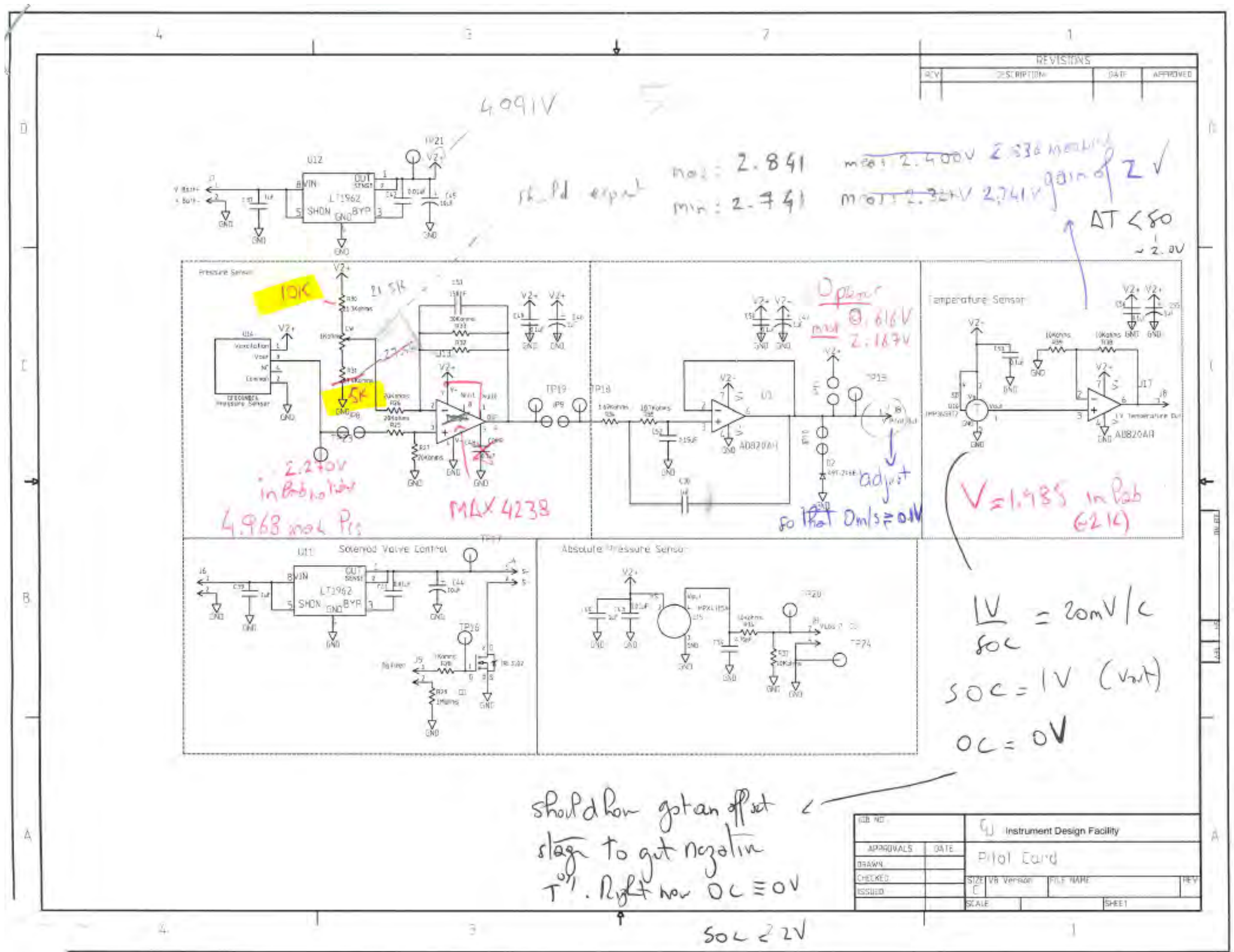


Figure 27: Pitot Card Schematic

The Pitot card conditions the signal of the differential pressure sensor that is connected ato the dynamic and static ports of a pitot tube. In addition, the card also contains 3 other auxiliary circuits for measuring absolute pressure (later calibrated to altitude with the GPS altitude measurements), the package's internal temperature, and a circuit that control a solenoid switch.

The purpose of the pitot card is to make windspeed measurements with a pitot tube which will later be used for calibrating the raw voltages of the hot wire anemometer. The pressure difference between the dynamic and static ports of the Pitot tube (model 166-6 Pitot tube from Dwyer instruments) is measured by a Honeywell DC001NDC4 differential pressure sensor. The 0-5V sensor has an output voltage centered around 2.25V and a dynamic range of ± 1 in H2O (±2 V). Since we only use the pressure sensor to measure positive pressures (with respect to the static port), circuitry is used to offset the zero pressure voltage back to ~0.2V and then add some gain so that the 2V dynamic range is ma the 0-2.5V input voltage range of the digitizer.

Since the selected model of the differential pressure sensor measures pressures of ±1 inH2O, the maximum windspeed that can be measured is:

$$\sqrt{\frac{2\Delta P}{\rho}} = 20.3\ m/s$$

Which is sufficient for balloon based boundary layer applications.

Assuming R1 to be the combined resistance of the top resistor of the offset stage and of the portion of the trimming potentiometer between the top terminal and the wiper, and R2 the combined resistance of the resistor connected to ground in the offset stage plus that remaining portion of the trimming potentiometer, the output voltage of the Gain+offset stage is:

$$Vo = \left(1 + \frac{R33}{R26 + \frac{R1 \times R2}{R1 + R2}}\right)V_{IN} - \left(1 + \frac{R33}{R26 + \frac{R1 \times R2}{R1 + R2}}\right)\frac{R2 \times R33}{(R33 + R26)(R1 + R2) + R1 \times R2}\ Vref$$

Therefore both the gain and offset are affected by adjustments of the trim pot (slight effect).

With the values chosen for the circuit, at 0m/s the output voltage can be adjusted anywhere from 0.24V to 0.63V and the corresponding gain for these extremes are 1.13 and 1.14 respectively. At 2.5V, the windspeed will be 20m/s and18.56 m/s respectively.

Before using a payload, check the output voltage of the pitot card at 0m/s. Make sure that the offset is set to the desired operating point as this determines the maximum windspeed that can be measured.

Reason for the solenoid switch:

The specs provided for the differential pressure sensor however do not show the effect of temperature on the gain since all specs are for measurements made at 25C. Therefore, in order to account for the effect of temperature on the gain of the differential pressure sensor, measurement of the pressure difference between the static port and itself are collected using a solenoid switch to switch between measurement of the dynamic pressure with respect to the static pressure and the between the static port and itself.

The solenoid is controlled by the DAQ which sends a repetitive square wave signal that goes low for 57 seconds and high for 3 seconds. This signal feeds the gate of MOSFET. The Vgate threshold voltage is less than the 5V output by the DAQ for the high portion of the square wave. When the gate is set at this voltage, current flows between the source and the gate and now that the – terminal of the solenoid is connected to ground, the solenoid is now energized by the voltage reference switching to measurements of the static port with respect to itself. Changes of the dynamic pressure due to temperature changes and not windspeed can therefore be calibrated out of the dynamic pressure data by fitting the time series of reference pressure measurements.

The last stage of the circuit is, like the thermistor cards, an anti-alias filter with cutoff frequency set to 75Hz (since the pitot data are sampled at 100Hz).

The voltages of the pitot tube are calibrated to m/s by collecting data in a wind tunnel (see calibration section).

5 Batteries Power Draw Considerations

We have 4 battery packs:

- One battery pack for the HW and CW cards providing V+ and V-
- One Battery Pack for the DAQ and sparkfun: V+ only
- One battery Pack for the Thermistor cards, Pitot card, GPS and serial interface
- One battery for the solenoid switch

The battery packs are mode from 3.7V 1000mAh single cell lithium batteries

Two are put in series to make one 7.4V battery.

The HW and CW battery pack therefore has 4 single cell batteries.

The DAQs battery pack uses 6

The Pitot uses 4.

The solenoid battery uses just 2.

The draws from each module are:

-HW/CW: draws 64 mA on V+ (14mA from CW and 50 mA from HW)

-HW/CW: draws 16 mA on V- (7mA from CW and 9 mA from HW)

- The DAQs draw ~300 mA

- The pitot, therm, serial, GPS modules draw altogether: 120 mA

Since the single cell batteries are 1000mAh so:

- For the hw/cw, a single pack will last 15 hours.
- For the DAQs; the triple pack provides 3000mAh so will last for 10 hours.
- For the pitot, serial,… the double pack will last for 2000mAh/120mA = 16.6 hours
- The solenoid battery will last a very long time.

6 System quality control procedures

To verify the proper functionality of each turbulence payloads, modules are first tested individually. Only the DAQ, HW, CW and thermistor cards are tested in this manner. Testing of the remaining modules will be done when the package is fully assembled.

First, each circuit should be powered with the lab power supply to verify that there aren't any unusual draws. The current draws to be expected for each board are reported below for each module. The second step involves verifying with a voltmeter that the voltages at different test points are sound. Lastly, benchmark data should be collected using the DAQ. The first step is therefore to make sure that the DAQ itself works properly. Once it is determined that the DAQ works, one can collect benchmark plots for the CW and HW (using the onboard dummy probe). Then a full payload can be assembled and final benchmark plots for each signal can be generated (still using the dummy probes onboard the CW and HW cards).

Following is a list of procedures taken to test each module followed by procedures for testing the fully assembled package.

6.1 DAQ benchmark plots

To test the DAQ, we will simply feed to all the available ADC channels a clean known voltage, digitize, and check that all channels digitize the signal without glitches, and the voltage divider at the input of the channels are correct (some divide by 2 and some by 6). Spectra of the clean voltage collected on both HF chips will also be computed to check for cleanness and interferences. The cleanest signal we could think of using is that of a 1.5V lithium battery (AAA). The voltage from a lab power supply would not be as clean because of 60Hz.

Following are the steps taken for testing the DAQ:

- Power Supply Requirement: Single supply. Connect with at least +6V.
- Connect DAQ to power and verify that the Green LED turns on (indicates that DAQ is powered).
- Verify that the power draws are appropriate. Expected draws for the DAQ:
  - ~200 mA when data writing to Flash card (indicated by Red LED flashing)
  - 176 mA when not writing (DAQ4 at least, DAQ2 250mA?).
- Disconnect power and connect each input terminal with a known voltage.
  - We use a bread board and a 1.5V battery (see Figure 28).
  - Connect the ground of the 1.5V battery to one of the input for ground (they are all connected).
  - Connect V+ of the 1.5V battery to each analog input of the DAQ except A8 and A9 (i.e. connect to HW+, CW+, A1-A16). Note that the other block terminal with labeled D01- D03 are not input channels but output channels (a digital switch signal generated by the DAQ).
- Use a computer to format the Flash Card (format to FAT).
- Insert the flash card into the DAQ and power up the DAQ (or power up the DAQ and insert the flash card). The green LED should be lit up when the DAQ is powered up and the red LED should also lit up when the Flash card is inserted indicating that data are being written to the flash card.
  - NB1: do not push hard if the Flash card does not seem slide in nicely. Sometimes the pins of the connector might be bent or the holes of the flash card do not align with the connector and pushing hard will just bend them more. If the DAQ does not connect

nicely, investigate why. Verify that no pins are bent, and also make sure that the flash

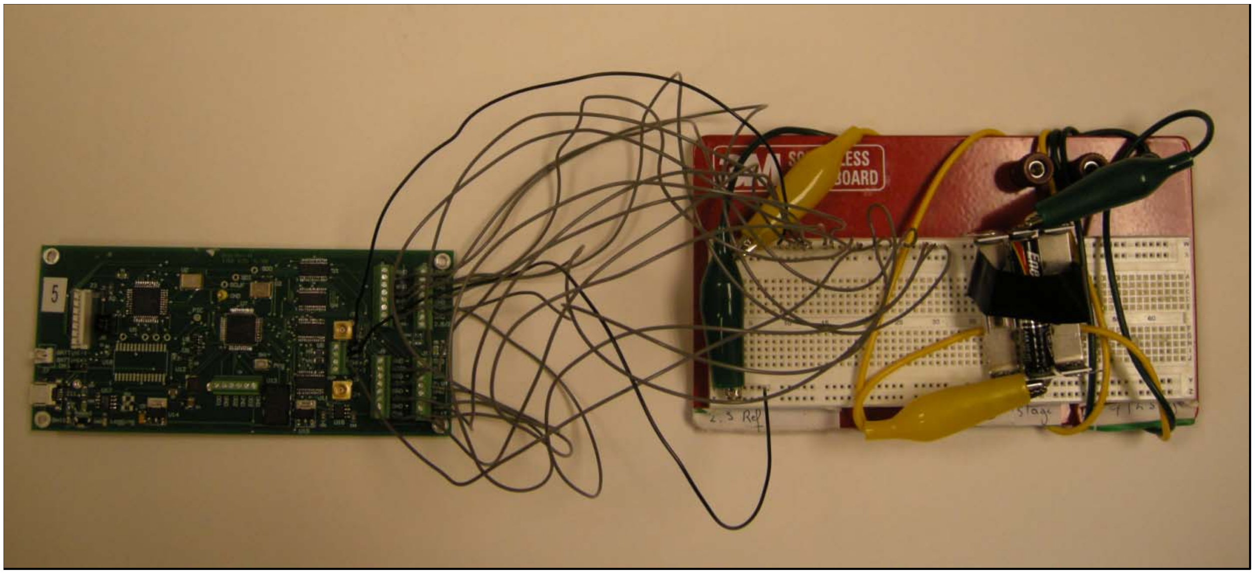


Figure 28: DAQ channels calibration

card receptacle is securely connected to the DAQ.

  - NB2: it should take about 1 sec for the red light to turn on once the Flash card is inserted. We've had issues with DAQs where the light would not turn on. Had to turn DAQ off and back on until it worked. Sometimes it might be because a pin was bent.
- Using a voltmeter and while data are being written to the flash card, measure and archive to a text file the exact voltage being fed to the channels of the DAQ.
- Collect data for at least 20 minutes since the DAQ takes about 10 minutes to warm up (i.e. even the 2.5V reference voltage will not stabilize until after 10 minutes).
- Remove the flash card or power off the DAQ
- Copy the CFDATAxx.DAT file to your computer and use the IDL program to generate benchmark plots:
  - Raw time series of the HF channels: 001_b_Time_Series_Diagnostics_Raw_HF_channels_raw.ps.
  - Time series of LF_Chip1: 001_c_Time_Series_Diagnostics_Raw_LF_chip1.ps ()
  - Time series of LF_Chip2: 001_d_Time_Series_Diagnostics_Raw_LF_chip2.ps.
  - Spectra of HF_chip1 and HF_chip2.

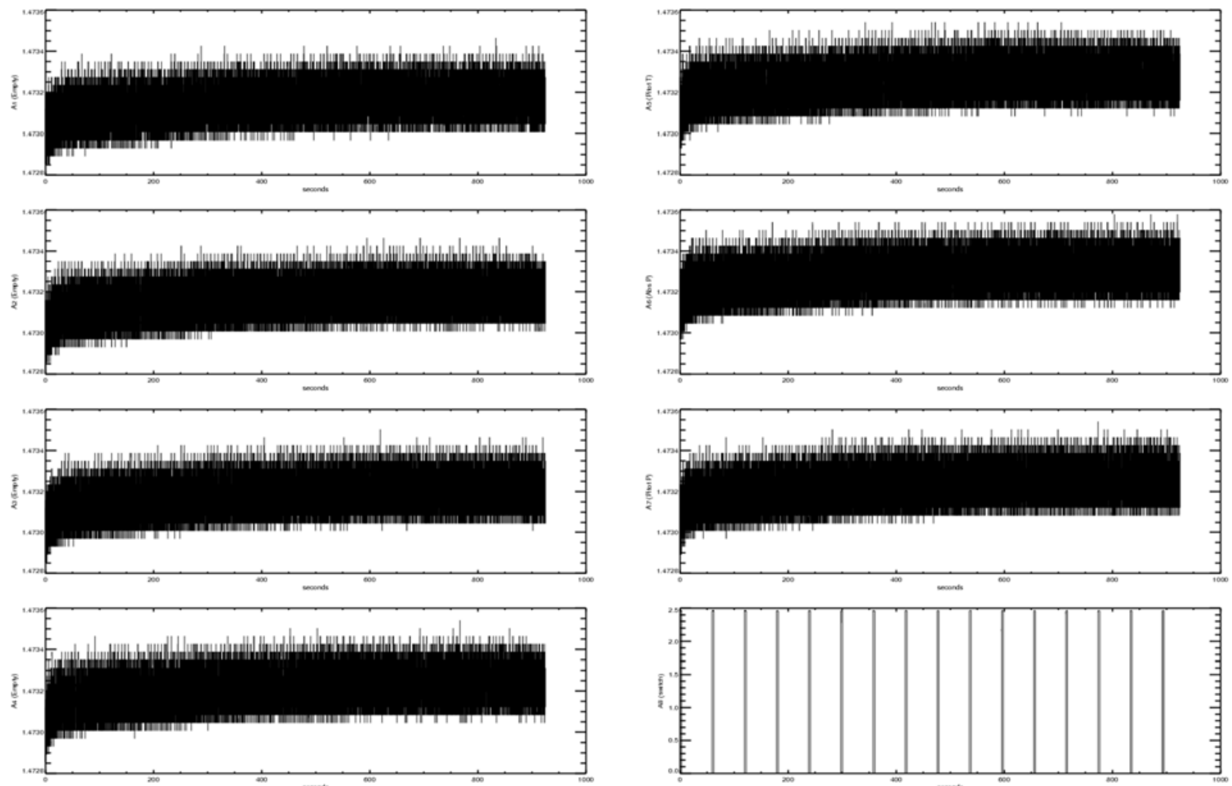


Figure 29: LF Chip1 Diagnostic Plots

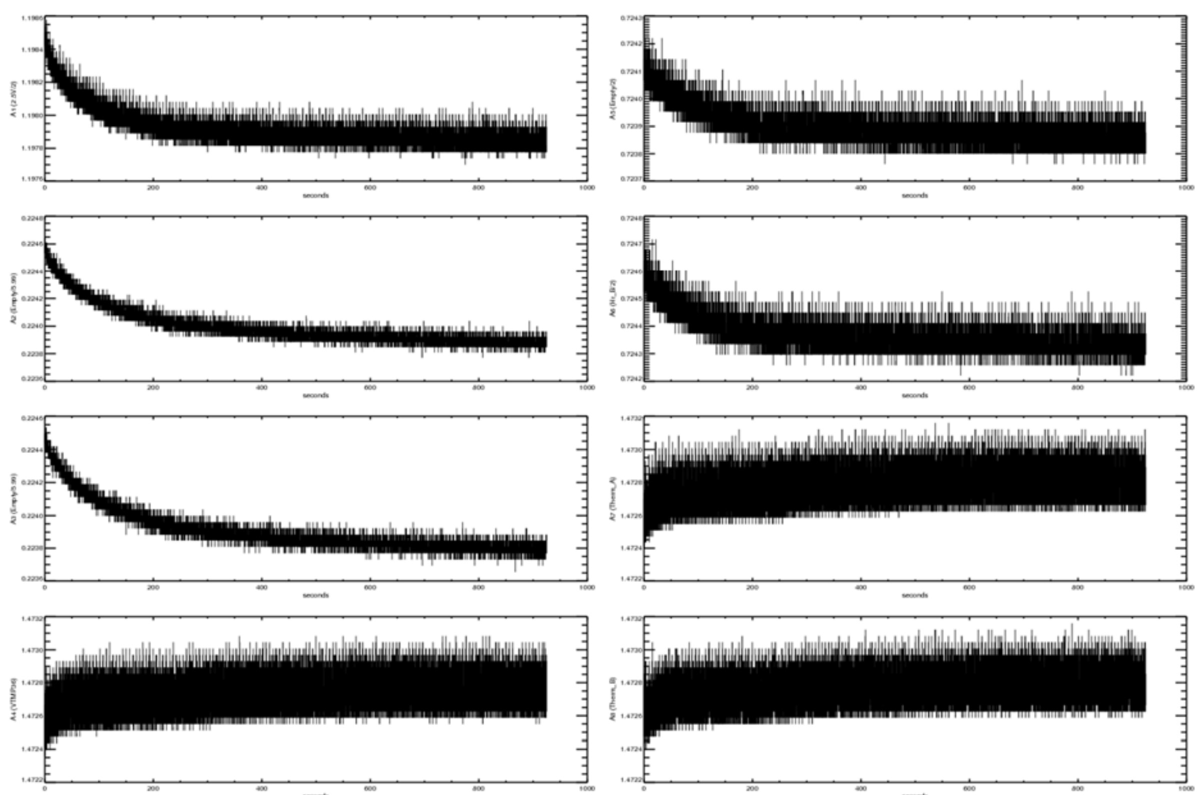
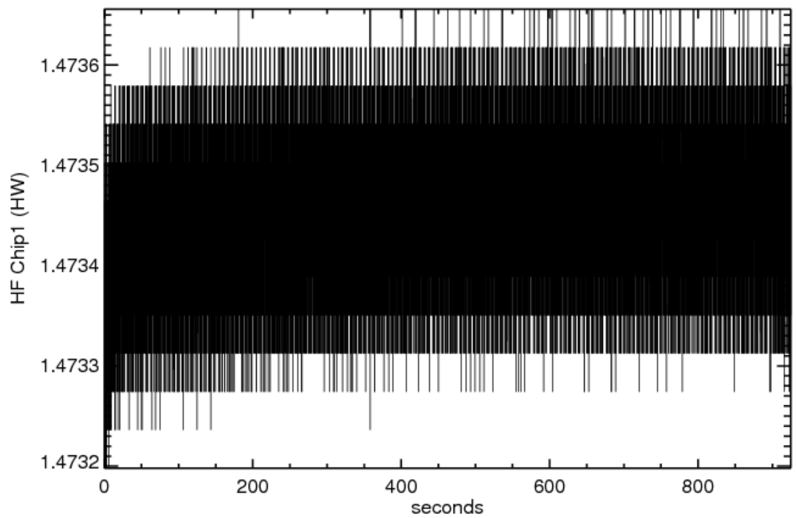


Figure 30: LF Chip2 Diagnostic Plots



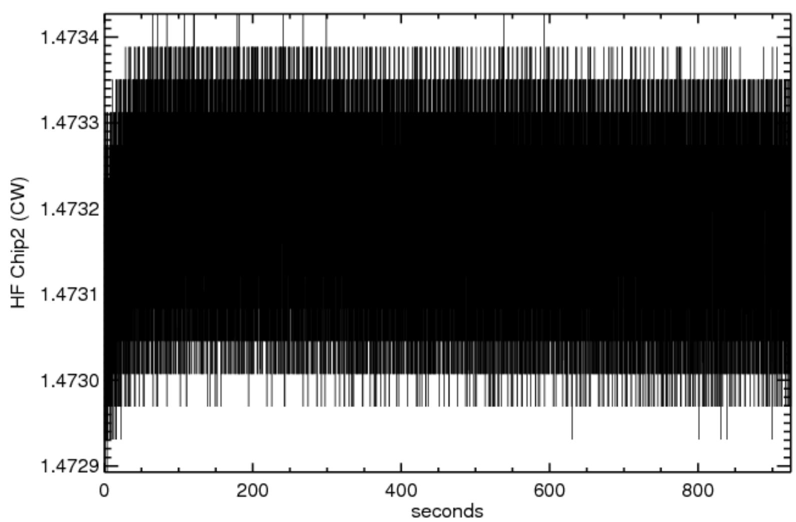


Figure 31: HF channels

Things to check:

- Knowing that ~1.5V was fed to all 16 LF channels (except A8 and A9), check the levels of each channel. Some of the channels have voltage dividers to allow for the optional logging of signals outside of the 0-2.5V range. For example, channels A13 and A14 were initially designed to receive the output signal of the humidity sensor. Because at 100% humidity the humidity sensor has an output voltage of almost 4V, A13 and A14 have a voltage divider of 2. Therefore, the voltage digitized in those 2 channels should ~1.5/2 V. Likewise, A10 and A11 have a voltage divider of 5.99 and the voltage there should be ~1.5V/5.99 = 0.25 V.
- Check that A8 correctly shows the switch pattern (repeating pattern: high for 3 seconds and low for 57 seconds).
- Check that A9 is 2.5V/2 (reference voltage).
- Check the two HF channels have the correct voltage of the battery (~1.5V).
- Because the signal is so clean, all we see in the time series is the bit noise around the 1.5V voltage.

The data collected in this test are also used to calibrate the offsets of the DAQ's channels. For example if we were to feed the pitot signal to another channel than the one used when performing the

wind tunnel calibration of the pitot tube, we would need to know how to correct for the different offset between each channel. Each channel has its own absolute offset and since we took note of the real voltage of the battery, we calibrate for those offsets when running the data processing code after collecting real data. It is required for sensors like the humidity and TMP37 temperature sensor of the thermistor cards since those sensors are already calibrated.

6.2 CW benchmark plots

To test the CW, we use the on-board test resistor (Jumper 47) which is a resistor with the same resistance as the resistance a real probe would have. That resistor, which to some degree is insensitive to temperature changes, gives the cleanest possible signal for producing benchmark plots.

Steps to test the CW are as follows:

- Connect Jumper 47.
- Using the lab power supply, provide +Vs (6V or more) and –Vs (-6V or less) and check that the card has no huge current draws. The CW should be drawing 14 mA at its positive terminal and 7 mA at its negative terminal.
- Check the voltages at of test pins located on the edge of the board:
    - Pin1 (left most pin), TP3: GND.
    - Pin 2, TP4: the output of the 2.5V regulator. Reading should be very close to 2.5V (e.g. 2.499V).
    - Pin 3, TP6: By adjusting the R7 trim pot, you should be able to set this test point to 10 mV.
    - Read the next test point to the right (TP8). It should also read 10mV.
    - TP9 is the output of the first stage gain (LT1028). No check required here.
    - Read the next test point, TP12. This is the output of the second stage buffer+gain OpAmp (OP97). By adjusting the offset trim pot (R3), you should be able to set that test point anywhere from 0V to 2.5V. For testing purposes, set it to 1.5V.
    - Read the last test point. This is the output of the anti-alias filter. The voltage should be exactly the same as the previous test point since the filter only cuts above 400Hz (low-pass filter with cutting frequency of ~400Hz).
- Connect to the DAQ, collect a time series (**Error! Reference source not found.**)
- The time series should show no major drifts since the dummy probe's is virtually insensitive to temperature (not a sensor). However, some drift is expected in the first 10 minutes of operation as the electronics components are warming up. For comparison, see the CW time series of Figure 33 which exhibits abnormal drifts.

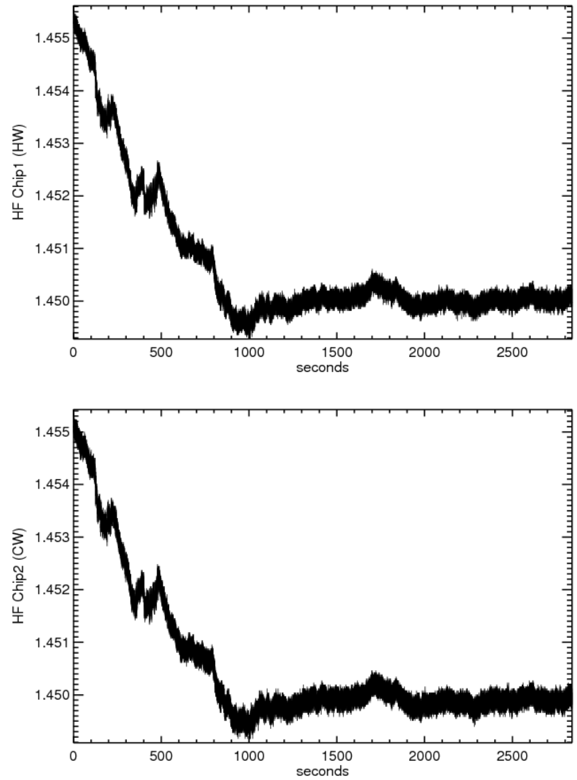


Figure 32: CW time series (dummy probe)

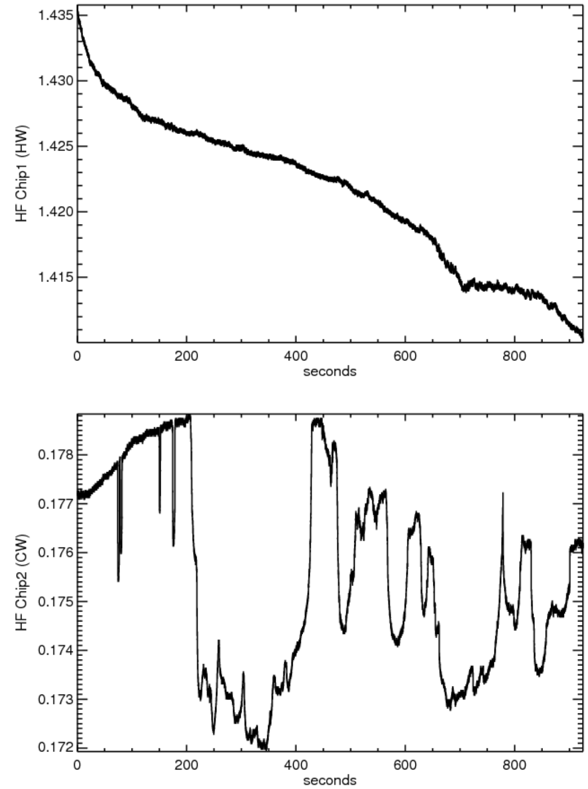


Figure 33: HW and CW time series (dummy probes)

- The next step consists of generating a spectrum of the dummy probe's time series and check the shape of the spectrum. We select a region of the time series that is well behaved and average a number of 10-seconds spectra to beat down the noise.
- Things to look for in the spectrum:
    - The noise floor should sit close to3e-12 V (i.e. the noise of the LT1028 first stage opamp tiems the total gain of the circuit G~2000).
    - The spectrum should merge to the flat noise floor around 100Hz.
    - The anti-alias filter is set to start acting around 400Hz. If the spectrum starts deviating from the flat noise floor before the 400Hz or if the drop is too abrupt, the components (resistor and or capacitors) of the last stage low-pass sallen-key filter are probably wrong. Verify that the right values were used.
    - There shoudn't be any interference or harmonics larger than the ones shown in Figure 34.

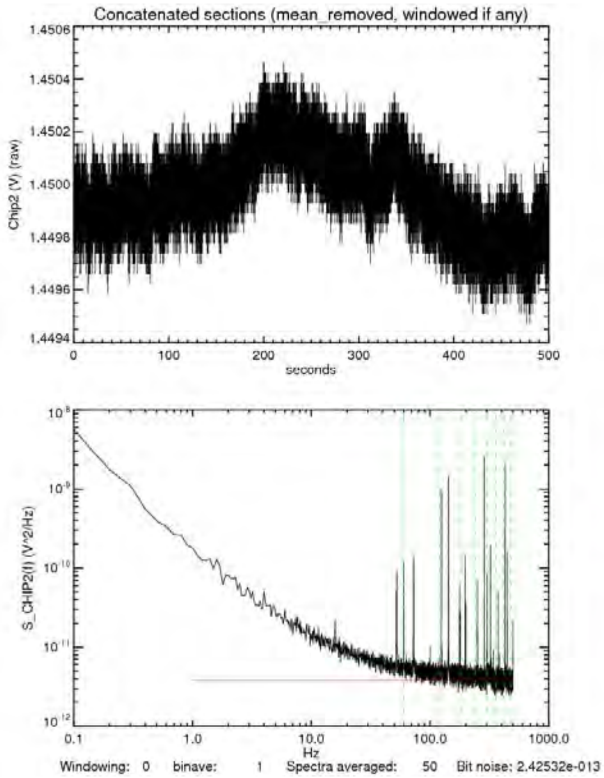


Figure 34: CW spectrum (dummy probe)

Debugging precautions:.

- Check for unusual current draws on the + and – terminals.
- Make sure that the jumper for the dummy probe is connected (JP47)
- Make sure that we have both R54 and R53 installed (should be both 10 ohms).
- Check the output of the 2.5V voltage reference at TP4.
- Check the outputs of the two regulators. Check TP11 for -5V. Check TP10 for +5V
- Check again each test point between each stage and see where the problem starts
- Check each opamp/stage:
    - o U4 (MAX6126) pin2 should be +5V. Pin 7 & 6 should be 2.5V.
    - o U2 (LT1028): pin 4 (via JP30) should be -5V, pin 7 (via JP41) should be +5V. Make sure that R63 is not populated, R9 not populated,
    - o U3 (OP97): pin 4 (via JP31) should be -5V, pin 7 viaJP42 should be +5V. Make sure C6 (to the left of JP31 on board) is not populated.
    - o U1 (AD820): pin 4 via JP45 (0 ohm on right-hand-side pad) should be GND. Pin 7 (via JP39) is +5V.
- Important: if the spectrum at the final output (with dummy on-board probe) shows a drop around 400Hz and a noise floor that does not flatten out at ~3.10^{-12} V^2/Hz but 4.10^{-13}, change C2 and make sure to put a 0.0068uF (6800pF) capacitor there (and not 0.068uF=68000pF).

6.2.1 HW benchmark plots

Just like for the CW board, we will generate diagnostic plots using the dummy probe to produce clean spectra and check that they have appropriate shapes.

- Connect jumper 51 (dummy 10 ohms probe)
- Make sure the red toggle switch is pushed to the left (when facing the board/switch).

- With the lab power supply, Power up the card with +Vs and –Vs.
- The leftmost pin is ground.
- Check the 2.5 V reference test point (second pin).
- Connect to the 3rd pin. Using R29 (leftmost trim pot), you should be able to set the next pin to -0.8V (the full range of the swing should be 0V to -3.170V).
- Check the current draw on +Vs (50 mA expected) and –Vs (9 mA expected).
- The voltage at TP25 after setting -0.8V at TP23 should be +1.431V.
- TP28 is the output of the offset stage set by the second trim pot (R30). Set fully counter clockwise you should get ~2.217V and set fully clockwise should give -2.420V.
- Set TP28 to 0.2V.
- The voltage at the last pin (TP29) should be the same as the previous one since that last stage is just an anti-alias filter.

Bugs encountered during testing of previous cards:.

- R51 should not be populated (there is already a 10 ohm resistor).
- R29 should be a 10K pot and not a 100K.
- Check the output for the regulators (TP26 for +5V and TP27 for -5V)

6.3 Testing of the Pitot Card

This card is tested with the fully assembled package.

General:

As usual, make sure that all connections work as sometimes the wire that you squeeze in those tyco connectors/wire housings (e.g see Mouser part # 571-3-640441-3) does not make contact. For example, we had a pitot card that was not providing any output voltage. That was because even though the pressure sensor was powered correctly, the yellow wire of its output voltage was not making contact with the plug.

Pressure Sensor:

When checking the Pitot card, first verify that the output of the pressure sensor is something around 2.1V (specsheet calls for 2.25V at 0 pressure but that number varies from pitot card to pitot card).

For example for 2 different pitot cards we got 2.195V and 2.270V at the output of the pressure sensor.

Make sure that the output voltage of the pitot card can be set with the trim pot to 0.1V in the lab since that's where we want the voltage to be at 0 windspeed. Take note of that voltage for each board and maybe even put a label on the pitot card for future reference since the pitot card is then calibrated in the wind tunnel with such settings and if there is a long term drift or if the pot is even turned by mistake, you want to be able to correct for that in order for the wind tunnel calibration to still be valid.

TMP36 temperature sensor:

You can just verify that the voltage makes sense after collecting data with the DAQ. The TMP36's output should ~0.8V @ 25C. However because the circuit was initially using a different temperature

sensor which output voltage had to be doubled to take the whole 0-2.5V voltage range of the DAQ input, we have a gain of 2.

Therefore the Pitot temperature sensor should output something close to 1.4V at room temperature. That is later divided by two by a voltage divider attached to the input channel of the Pitot temperature sensor.

6.4 Testing of the Thermistor cards

The thermistor cards use are composed of a thermistor circuit to measure temperature with a thermistor bead, and a separate circuit to measure either humidity with a HIH-4000 sensor or temperature with a TMP36 sensor. The TMP36 and HIH-4000 sensors have similar terminal layouts (+Vs, GNS, Vout) which allows to plug either of each into the connector pads of the thermistor circuit.

To test the thermistor cards, we simply make sure that the output of the thermistor circuit, humidity sensor, and temperature sensor provide voltages in a range that would be expected for room temperature measurements. A simple testing procedure to follow consist of:

- Pin Layout: When facing the pins of the thermistor card (top of the card facing up), the two left-most pins are for connecting power with the left-most pin the GND, and the second pin from the left +Vs. The middle pin (3^{rd} pin from left) is output of the optional sensor (either HIH-4000 humidity sensor or TMP36 temperature sensor). The next one is GND again and the right most pin is the output of the thermistor circuit.
- Power the card with the lab power supply.
- Check for unusual draw: should be ~ 3mA
- Check the output voltage of the thermistor: ~1.9V (@25C)
- Check the output of
    - the Humidity sensor:
    - TMP36 temperature sensor: ~0.8V at 25C
- Time series data will be checked once a full system test will be completed (data collected on DAQ once turbulence payload fully assembled).

6.5 Test of fully assembled package

- Verify cable connections: Verify the continuity for each cable you make. We use Tyco Headers/Wire housings for our cabling needs. These connectors do not involve soldering pins to the wires but instead, involve crimping the wire inside the connector. Sometimes, because the gauge of the wire is not appropriate for the connector, the wire might not connect to the terminal. Thus, for every wire/cable, make sure that the wire connects with the terminal.
- Verify Power input connections: Before connecting any module, measure the voltage at the terminals of the cables meant to power the cards and make sure that the terminals are connected to +Vs, GND and when appropriate, –Vs.
- Power the HW and CW card, make sure the dummy probes are connected (and not the MCX cable of the probe mount), and set the output voltages to 0.2V for the HW and 1.5V for the CW. Make sure that this voltage can be measured on the DAQ at the +Vcw/-Vcw and +Vhw/-Vhw terminals. Note the HW and CW cards are connected to the DAQ via the MCX mini coax cables (J14 on the HW and J12 on the CW).
- Connect the thermistor cards outputs to the DAQ and make sure that the voltages measured on the DAQ are correct. Make sure that the outputs of two thermistor cards go to the appropriate DAQ channels ie.:
    - Temperature output of thermistor card ‘A’ to A15.
    - Ground of thermistor card ‘A’ to the GND terminal next to A15.
    - Temperature output of thermistor card ‘B’ to A16.

  - Ground of thermistor card ‘B’ to the GND terminal next to A16.
  - Humidity sensor’s output of thermistor card ‘B’ to A13.
  - Output of thermistor card ‘A’ TMP36 (temperature) to A12.
- Connect the card:
  - J7: +Vs on the left-hand side of the connector (indicated on circuit board).
  - Verify that the correct voltage feeds the connector.
  - J6: Meant to power the solenoid switch and receives the voltage of an isolated/independent battery.
  - Verify that the correct voltage feeds the connector.
  - J5: is connected to the D01 output terminal of the DAQ (digital switch). D01 is meant to be connected to the left pin of J5 (the one next to the TP16).
  - Connect the solenoid to J4.
  - Make sure the differential pressure sensor is connected to its pitot card connector (U14). Left-most pin is +Vs, middle is GND, right most pin is the pressure sensor output.
  - When facing the pins of the pressure sensor (tubing connectors facing up). Pin4 (right most pin) is +Vs, pin3 is GND, Pin2 is the sensors’ output. (Pin1 not connected).
- Connect the 4 outputs of the pitot card to the DAQ:
  - GND output of pitot card to GND terminal above PitP (A3).
  - Pitot Pressure voltage to PitP terminal (A3).
  - Absolute pressure output signal to DAQ’s P terminal (A2).
  - Pitot card temperature signal to DAQ’s PitT terminal (A1).
- Connect the Serial Card:
  - Add compass.
  - Make sure power cable bring in the correct voltages (no reversed terminals).
  - Connect the GPS sensor to the interface card (J11) and verify continuity of connector. When facing the pins of the GPS, the left-most pin is GND, Pin 4 is +Vs, pin 2 is yellow and pin 3 is blue (convention we used). When facing the interface card, pin 1 (lef- most pin) of J11 is +Vs, pin 2 is the GPS’s yellow wire, pin 3 is the GPS’s blue wire, and pin 4 is GND.
  - Connect J14 to the DAQ. Facing J14 the color-coded wires we have are:
    - Pin1 black.
    - Pin2 red.
    - Pin3 grey
    - Pin4 yellow
    - Pin5 white
    - Pin 6 & 7 : not connected
    - Pin 8 (right-most pin) black.
  - Make a cable with an 8-pin tyco header following the same connectivity convention on both ends of the cable.
  - Connect the cable to the DAQ’s J3 connector.
  - Verify continuity between DAQ and interface card.
  - Connect the interface card’s J10 connector to the sparkfun digitizer GND/RX/TX connector. Facing the J10 connector on the interface card, pin 1 is empty, pin2 if red, pin3 is white, pin4 is black. On the sparkfun, black goes to GND, Red is Rx, White is TX.
- Connect the DAQ and the sparkfun to power making sure again that +Vs and GND are correct.
- Connectivity to the batteries is made through the power card.

- The DAQ and sparkfun use their independent battery pack to get +Vs.
  - The CW and HW cards used their own set of batteries for +Vs and –Vs.
  - The solenoid uses its own battery for +Vs.
  - The remaining modules (thermistor cards, pitot card and interface card) use one last battery pack (+Vs).
- Pitot sensor connection: make sure that the tubes connecting the pitot tube sensor to the solenoid and differential pressure sensor are connected according to the picture shown below:

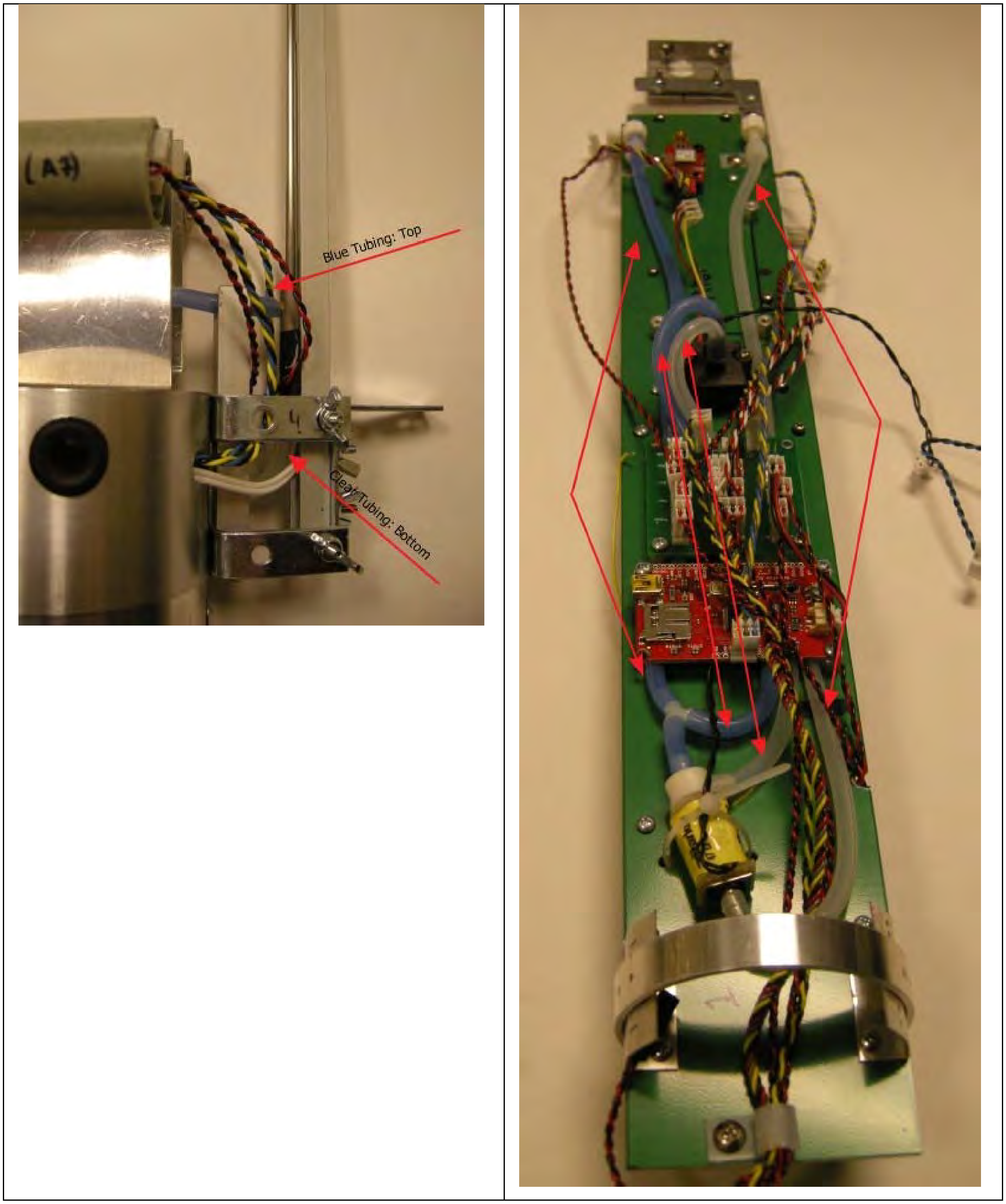


Figure 35: Pitot-Solenoid-Pressure Sensor Tubing Connections

- Verify one last time that all modules are connected:
    - Battery terminals to power card: 4 of them (for the HW/CW, DAQ/sparkfun, solenoid, and interface, thermistors, and pitot cards).
    - Power card to HW and HW
    - Power card to DAQ and sparkfun
    - Power card solenoid battery to J6 on pitot card
    - Power card to: Pitot, thermistor cards, interface card.
- Power up everything with the 3 switches of the battery cap.
- Verify that the LED on the GPS blinks. This indicates that the GPS antenna has locked onto satellites and the GPS is receiving data.
- After formatting Flash card and erase the files on the micro-SD card of the sparkfun (except for the LOGCON.txt file

MODE = 0
ASCII = y
Baud = 5
Frequency = 100
Trigger Character = $
Text Frame = 100
AD1.3 = N
AD0.3 = N
AD0.2 = N
AD0.1 = N
AD1.2 = N
AD0.4 = N
AD1.7 = N
AD1.6 = N
Saftey On = Y

Table 2: LOGCON.txt (note *Saftey On* appears as such in file. Not a typo made in this document)

- Power off the DAQs. Insert the flash card and SD cards into the DAQ and sparkfun.
- Turn the DAQs power On and watch for the Red LED on the DAQ.
- Collect data for at least 30 minutes and generated diagnostic plots.

Now that all the modules are connected, because they share a common ground from each module being connected to the DAQ, there will be some degree of interference due to the solenoid switch. Whenever the solenoid turns on, there is a current surge that can affect the other channels through the ground line. This is why the thermistor signals are collected on a different ADC than the one where the pitot data and digital switch are collected. The solenoid however does not affect the HW and CW signals, nor does it affect the signals of the thermistor cards.

Following are standard benchmark plots collected with the fully assembled package (HW and CW use the onboard resistors as dummy probes).

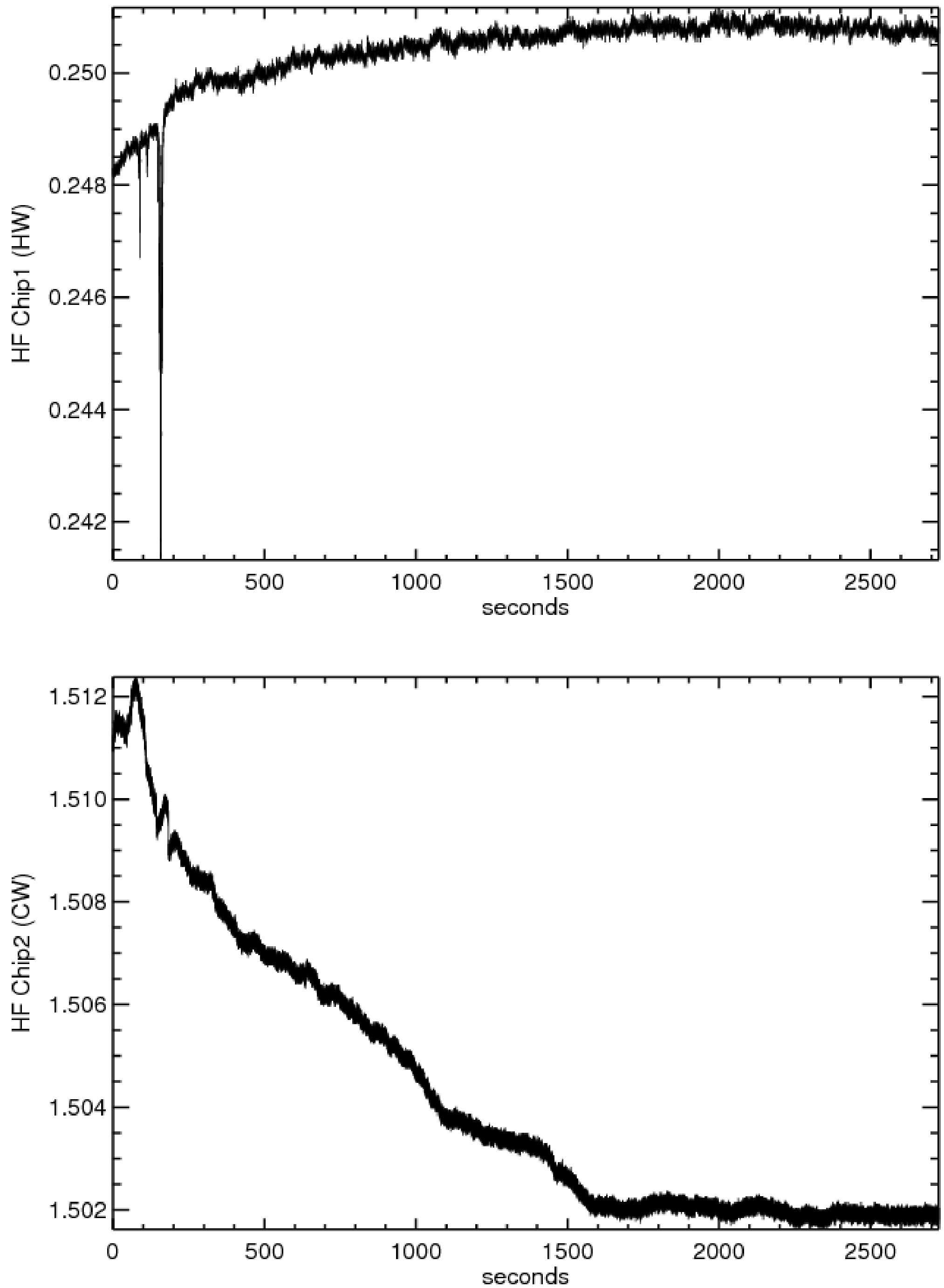


Figure 36: HW (top) and CW (bottom) time series (dummy probes)

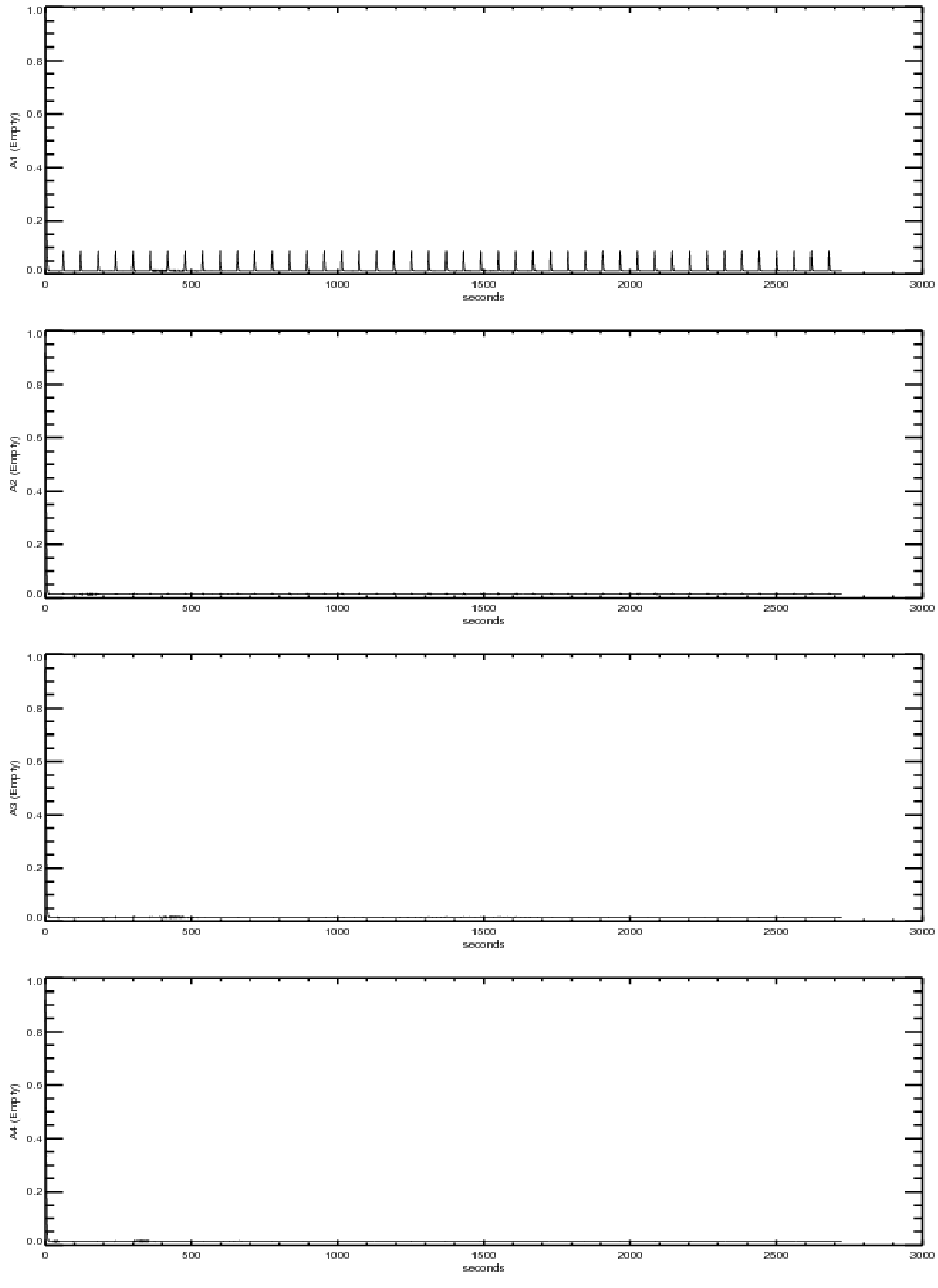


Figure 37: LF Chip1 Channels A1-A4

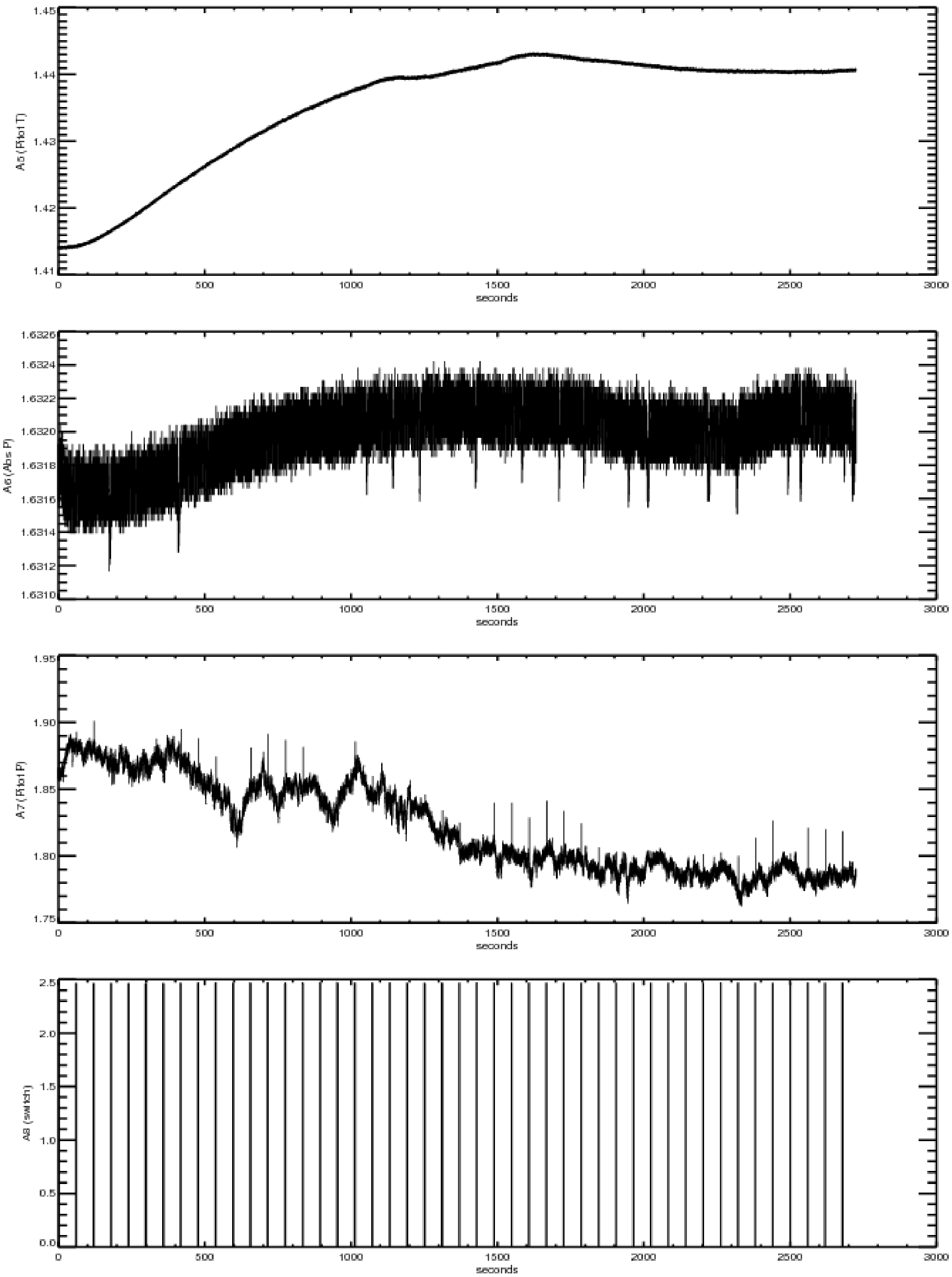


Figure 38: LF Chip1 channels A5-A8

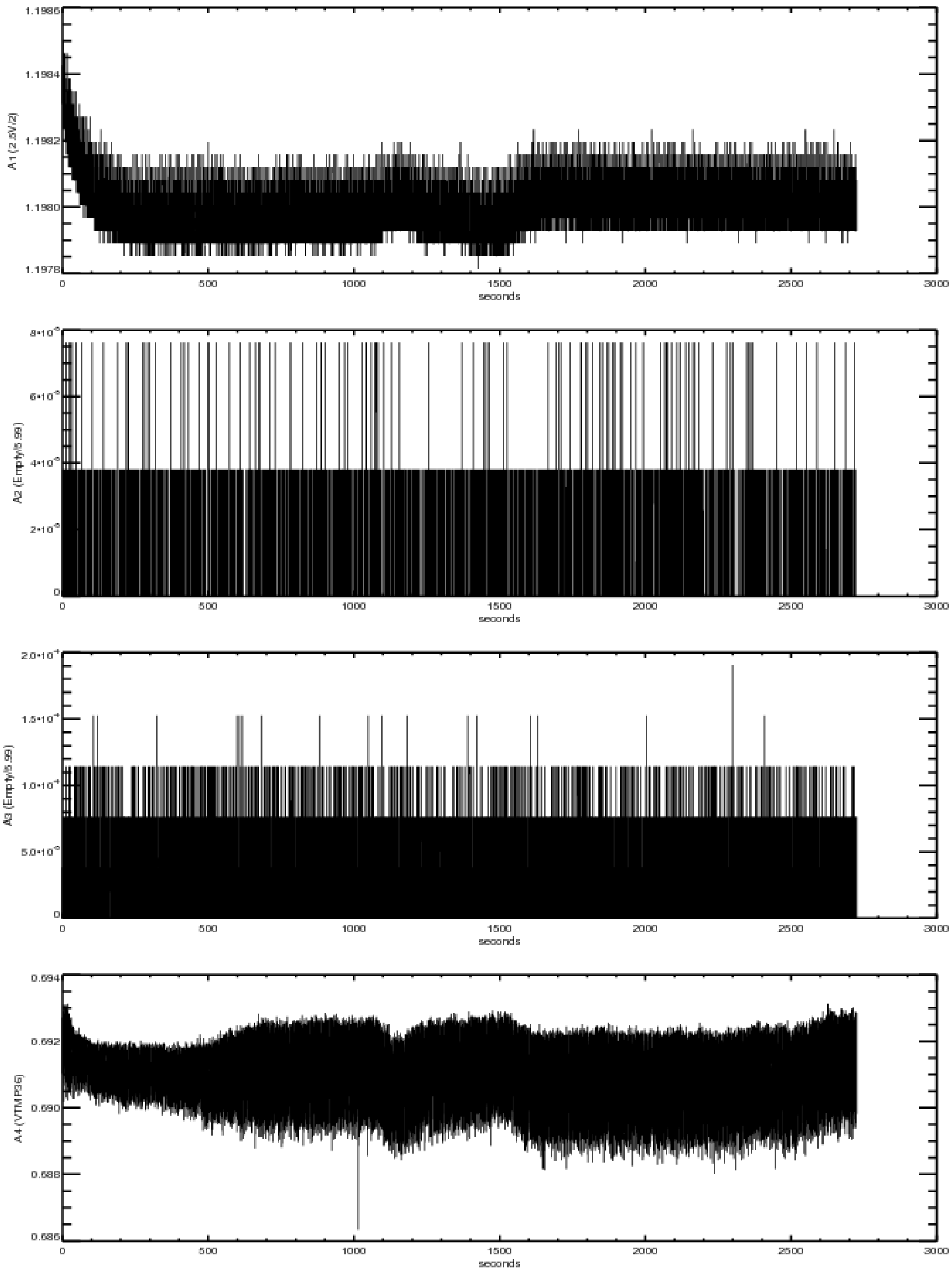


Figure 39: LF Chip2 Channels A9-A12

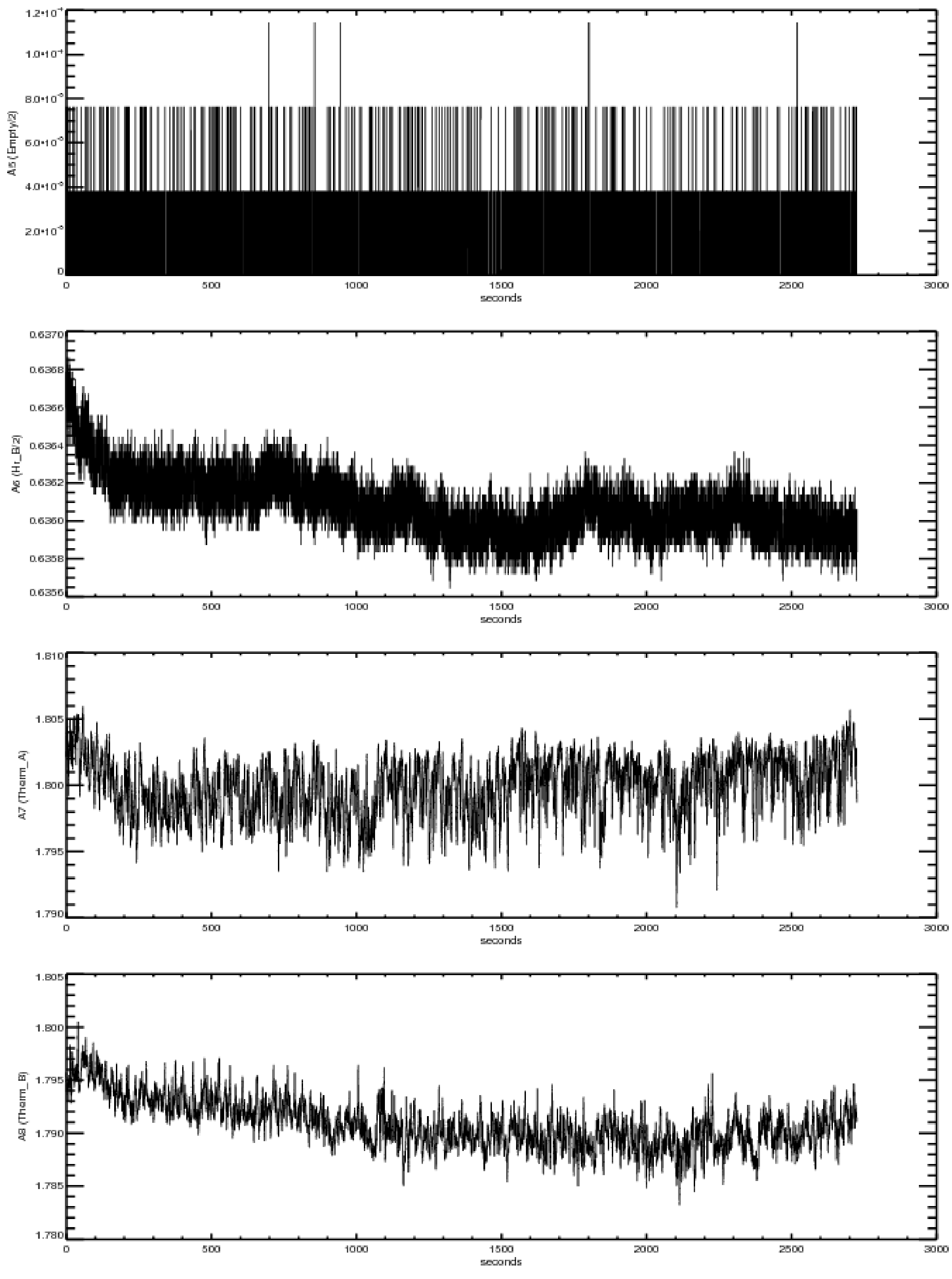


Figure 40: LF Chip2 Channels A13-A16

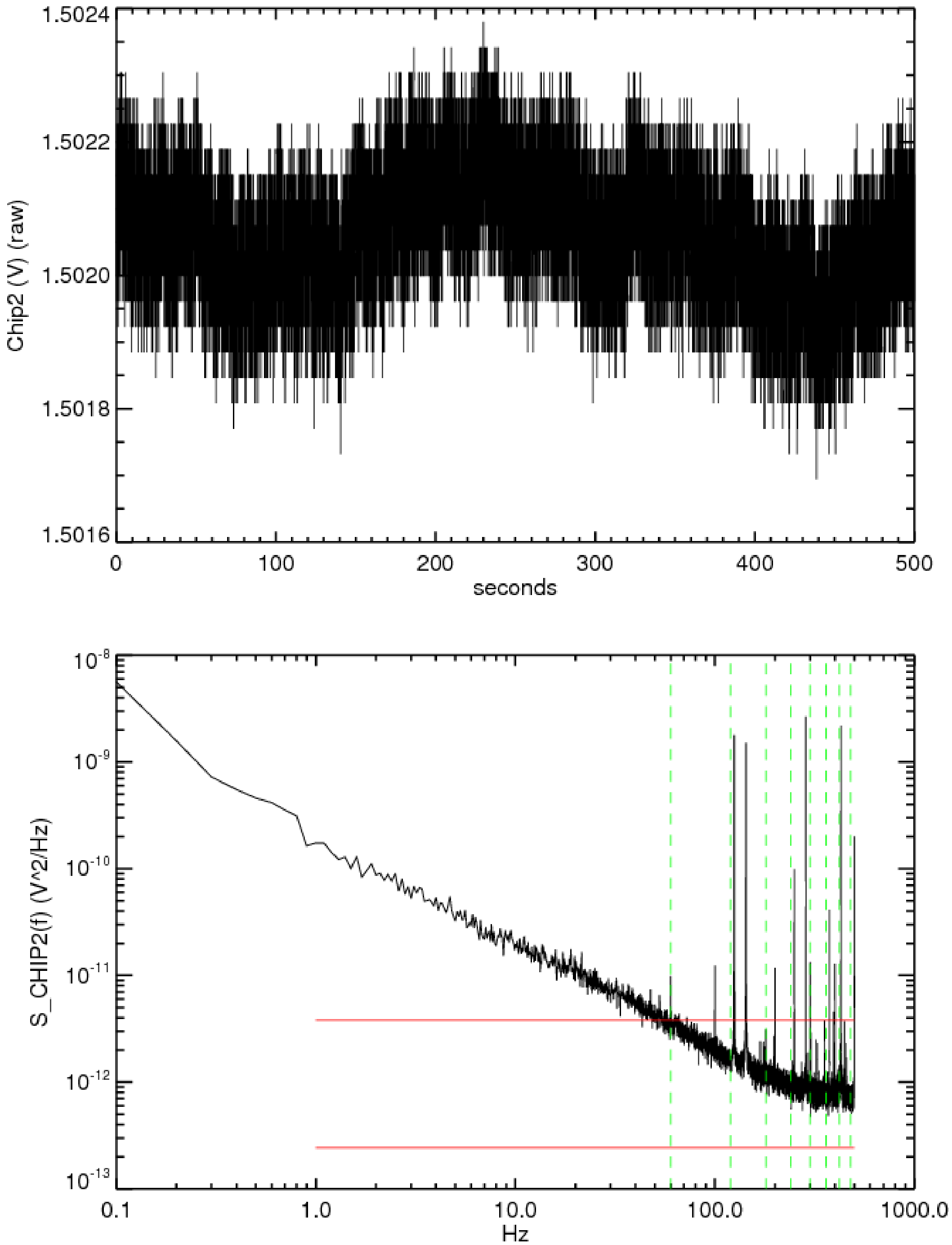


Figure 41: CW Spectrum (dummy probe) **(REPLACE PLOT: SEE FILTER EFFECT)**

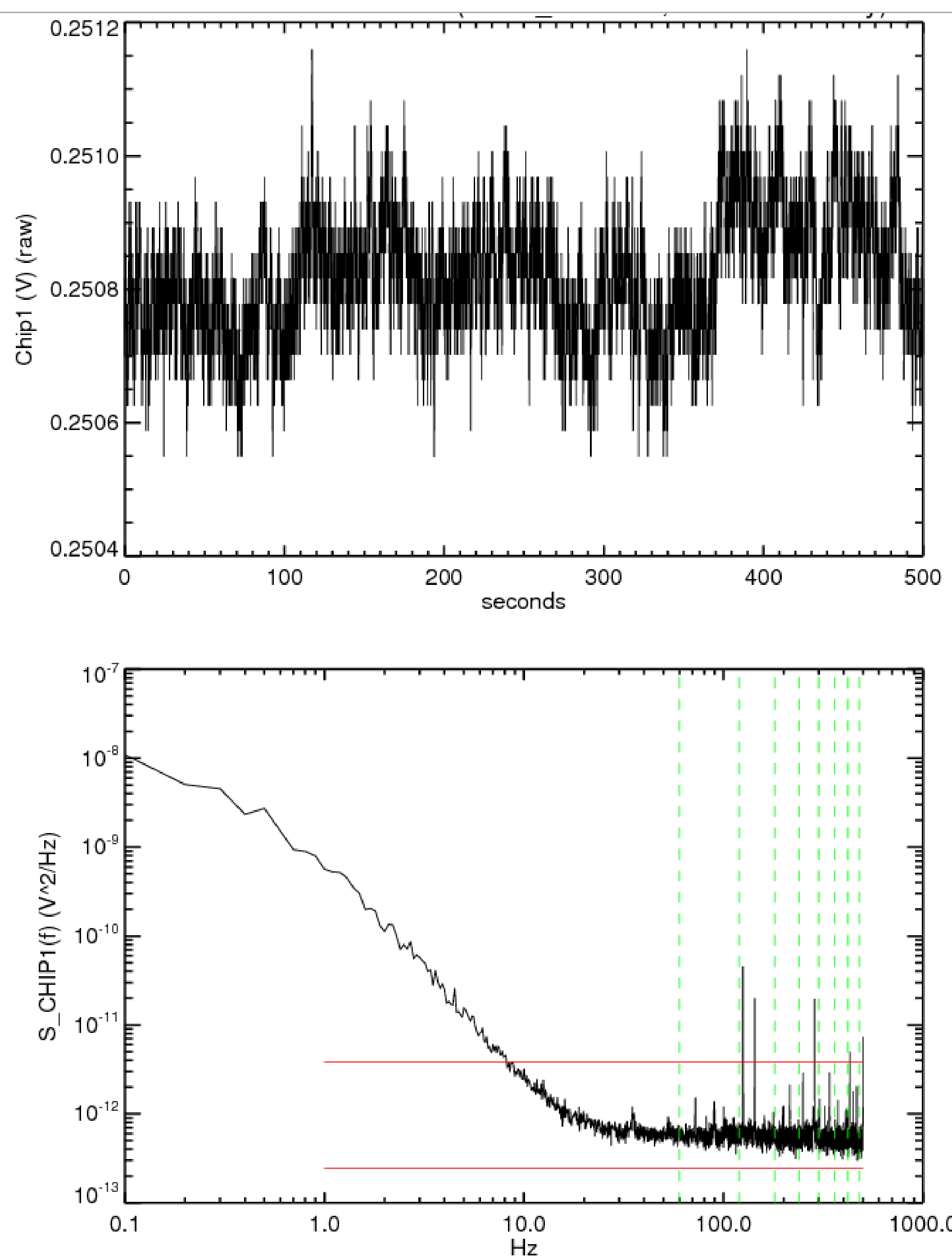


Figure 42: HW Spectrum (dummy probe)

7 CW overheat Ratios

Whereas preparing the CW for operation is just a matter of connecting the probe and making sure that the operating point is set at a voltage that will leave room above and below for temperature increases as well as decreases, operating the HW is much more tricky.

The reason is that the voltage to set at the input of the CW stage needs to be calculated in advance for each and every probe so that when the card is powered on, the hot wire probe is warmed up to the correct temperature, i.e. overheat ratio (usually 1.8). The voltage required at the input of the HW stage of the HW card for setting an overheat ratio of 1.8 changes slightly from probe to probe. However, small differences have a dramatic impact on the overheat ratio and using a standard value for all probes could lead to some of the probes burning up (5 micron tungsten can only be so hot before it oxidizes and eventually burns out) and in order to increase sensitivity of the hot wire probe to velocity (i.e. minimize the effects of temperature), the probe is operated at as high of a temperature as the material allows.

8 TP Batteries charging instructions

The batteries used to power the modules of the turbulence payloads are 3.7V lithium ion batteries (1000mAh). General guidelines for charging 3.7V lithium-ion batteries require a voltage of no more 4.25V and a current of no more than 1A.

The lab power supply is used to charge the batteries at a constant current. Since we use two of such batteries attached in series for our battery packs, the charging voltage is adjusted to 8V.

Even with the current limit of the lab power supply set to its max settings, the charging current is always less than 1A.

Batteries are charged until the current drops to tens of mA. Charge time is approximately 3-4h with the voltage of the batteries almost reaching full capacity within the first hour (constant current charge). For the next 2 hours, it goes in saturation charge phase during which the charging current gradually drops.

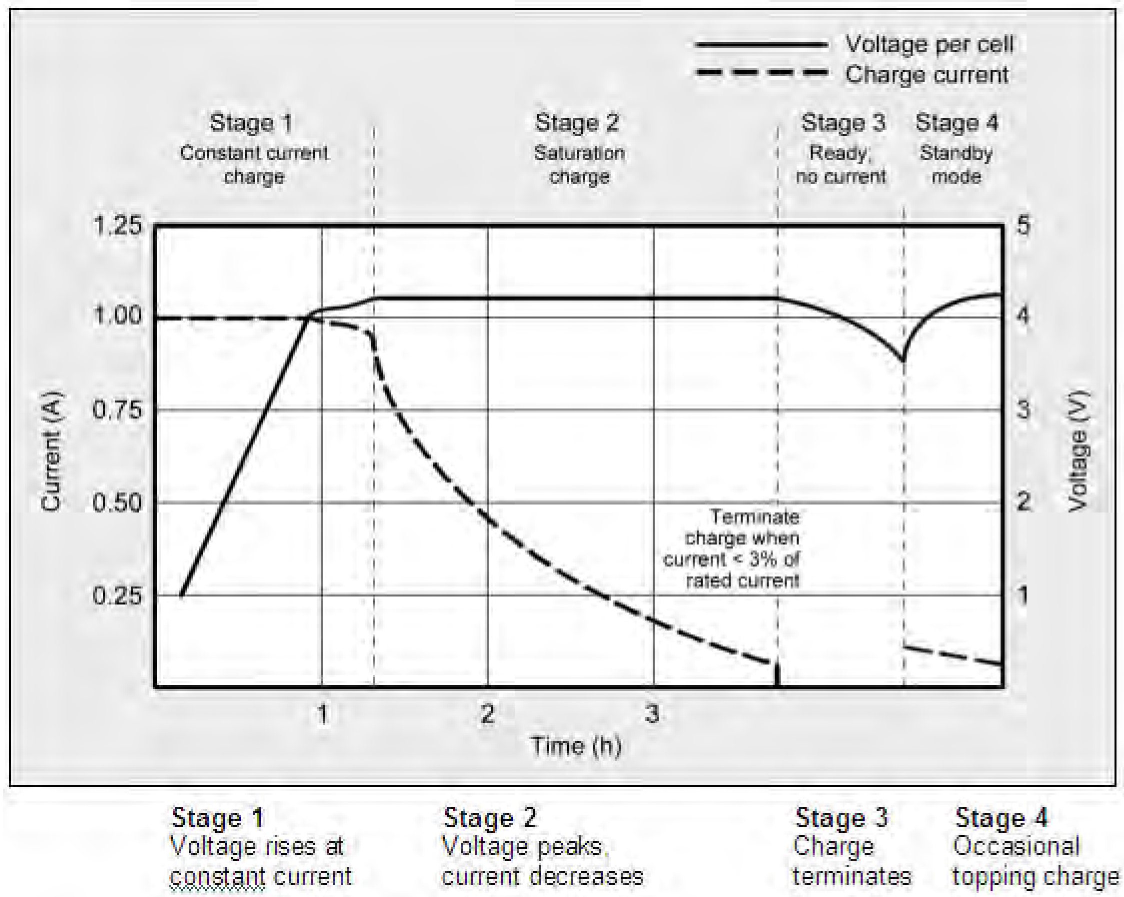


Figure 43: Charging curve of single-cell lithium-ion battery.

9 DATA cards

The DAQ flash card should be formatted to FAT.

The size of the SWAP file is stet by the DAQ (needs to be reprogrammed).

The data will be written to the CFDATA.DAT file.

The Sparkfun logger just creates text files. The first one is always called LOF01.txt but then the name goes to LOG##.txt

In order for the Sparkfun to run, you need that LOGCON file on it:

MODE = 0
ASCII = y
Baud = 5
Frequency = 100
Trigger Character = $
Text Frame = 100
AD1.3 = N

AD0.3 = N
AD0.2 = N
AD0.1 = N
AD1.2 = N
AD0.4 = N
AD1.7 = N
AD1.6 = N

Saftey On = Y

10 Field Operation Instructions

Setting the overheat ratio setting for each probe.

HW setting

CW setting

Warmup

11 Winch Operation

The winch is operated through the control box (Baldor) which manages the control of the motor and break. It can powered either directly form an AC outlet (Standard 15A 110V) or from a set of 24V batteries (two 12V batteries in series) after connecting to a 3500W DC to AC inverter. Control of the winch is performed through the keypad located at the top of the Baldor control box. Note that profiling cycles can also be automated by programming the control box (details below).

The break located below the Baldor control box locks in shortly after the winch is powered on in order to prevent the spool from releasing line out as a result of the blimp pulling on the line. The break is released for forward as well as backward operations, and closes again when the motor is stopped. Note that the break will be left open (unlocked) when the winch is powered off. Sometimes, when operating out of batteries and when performing measurements at constant altitude, the winch might be powered off to save power. To prevent the spool from releasing more line out, a lock pin is slid into the chain that connect the motor to the spool. When using the lock pin, make sure to put the warning tag/label on top of the display panel of the baldor control box as reminder to remove the lock pin before operating the winch again.

The 3.5HP motor is connected to a 5:1 gear box speed reducer which shaft is connected to the capstan from which the tether is reeled out. Note that it is the capstan that control the line release and reel in rate the large spool only keeping up with the capstan. This is why it is necessary to warp the line around the capstan 3 times in order for the capstan to grab on the line. The Kevlar line (1000lbs test) is fed out from a spool that is also connected to the shaft that drives the capstan to the difference that instead of directly driving the spool, the shafts of the gear box and spool are linked by a magnetic clutch. When

the winch is in forward mode (blimp goes up, line fed out from the spool), the capstan pulls line out from the spool while the spool freely rotates. A small amount of friction is maintained by the magnetic clutch in order prevent the spool from over-spinning after a sudden stop as a result of the momentum. In other words, the spool is not driven by the motor, it is just free spinning feeding line out to the capstan. When reeling the line back in, the spool is now directly driven by the same shaft that controls the capstan and the magnetic clutch allows controlling the amount of tension on the line between the capstan and the spool. This way the line can be packed onto the reel with just the right amount of tension. Too much tension and the line will be packed too tight on the spool causing the formation of grooves on the reel. Not enough tension and the line will be packed too slack on the reel.

As mentioned above, in order for the line to grab onto the capstan to prevent the line from sliding while the capstan is spinning, a few turns of the line around the capstan are necessary. Less and you don't have enough friction (line slips, capstan does not grab onto the line). More and the line will cross over itself during forward and backward motions. 3 turns are typically sufficient.

By default the winch is wired to operate at 110V but it can also be rewired for 220V (details below).

Power requirements:

The winch pulls 0.9A when idling. At full speed, the winch pulls 9.25A. Therefore, the winch can be powered from standard 110V/15A power outlets. The intermediary cable is required to connect the 4 prongs plug of the winch to the 3 prongs plug of the power outlet/extension cords.

Profiling Speeds:

The maximum profiling speed capabilities of the winch are set by the gear box's speed reducer. For the Army TLS, a 5:1 speed reducer was selected. With that gear box the maximum profiling rate is thus 3m/s which is good for emergency pull-downs.

	Capstan Ø	**Speed Reducer**		**Motor Power**	**Motor Speed**	**Motor τ**	**Capstan τ**	**Max Line Load**	**Max Line Speed**
	in	Ratio	% Eff	HP	RPM	in-lb	in-lb	lb	ft/s
English	6.40	5	90	3.0	1760	107	483	151	9.83
	cm					N-m	N-m	N	m/s
Metric	16.3	5	90	3.0	1760	12.1	54.6	672	3.00

Manual operation:

You can decide to run the winch just manually or you can program profiling cycles. When run manually, you just power the winch, the break will lock and the winch will wait for the command. Just press the FWD green button to indicate the direction to go and then start adding speed by pressing the up arrow key.

If the display does not show the speed in m/s but instead shows the motor speed in RPM, press the right or left arrows to switch between display modes. Note that in order to display the speed in m/s, the Baldor control box must have been programmed to tell it how many m/s correspond to a given rpm. Navigate the menu of the Baldor control box by choosing BASIC PARAMS > CUSTOM UNITS and the change the parameter VALUE AT SPEED. The table above shows the maximum motor rpm and the profiling speed corresponding to that motor speed (1760 rpm = 3m/s assuming that the balloon goes straight up).

When you want to go back hit stop. The winch will ramp down over a few seconds. Then hit Reverse. Upon hitting reverse, the winch will go in reverse mode quickly ramping directlyto the speed that was last

used during the FWD motion. Instead of hitting stop, you could also decrease the speed of the fwd motion and then hit stop once it is at 0. Then hit reverse and add speed. Lastly, you can also directly hit reverse when it is in forward motion. The winch will ramp down the fed motion, and rampup into reverse mode.

Not that when you hit stop, the winch activates the break. Sometimes, it might be preferable to save power (e.g. if powering the winch with batteries). So you might turn off the winch completely while the blimp is up collecting data at constant altitude or when it is sitting close to the ground. When the winch is powered off, the break is not activated and the blimp might start slowly going up as a result of its net lift or because of winds pushing the blimp downwind. This is why there a lock pin to stop the chain from moving. Of course if you leave the winch powered on and on stop, the brake is on and the blimp will not go anywhere but you do use power (0.9A).

Profiling Runs:

In profiling mode, as soon as the winch is powered up, the cycle will start automatically. The profiling cycles require programming the profiling speed for each ascent and descent legs, the number of profiles in the cycles, the duration of each ascent and descent. The different settings to change as shown below:

To set the general mode of operation (either profiling runs or manual)

Main > Basic Params > Opearting Mode : Profile Run

To adjust the parameters of your profiling cycles:

Main > Level 3 Block > Profile Run

# of Cycles

Speed Curve 1: Fwd Group 1

Profile Time 1: XX sec

Speed Curve 2: Rev Group 1

Profile Time 2: XX sec

You do have to set the speeds for each group used in your speed curve choices (e.g. Speed Curve 1 set to Fwd Group1):

Main > Adv. Prog. > level 1 block > Preset Speeds > Preset Speed 1: XX Hz

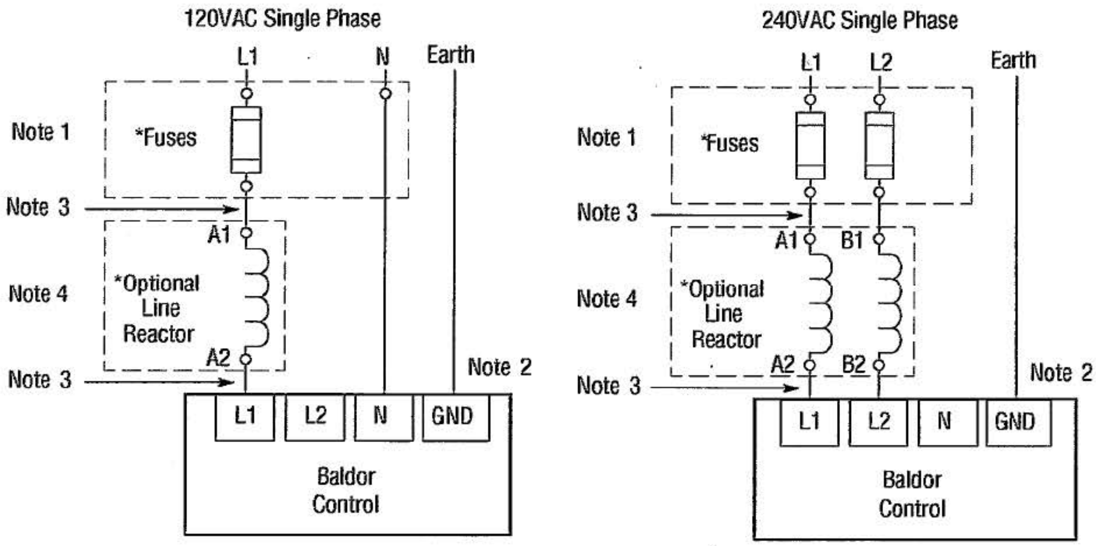
The speeds are in Hz though. So one needs to figure out how many Hz corresponds say 1m/s to know how to convert m/s to Hz. So operate the winch by itself with the line tethered to the spool. Set the speed for 1m/s and then using the left or right arrow keys, change the display of the LCD panel to display the frequency in Hz instead of displaying rpm or m/s. Use that to convert from m/s to Hz when setting the preset speeds. Note that there are other settings that can be adjusted such as acceleration times.

So to program a single ascent and descent and stop you would set Speed curve 1 to Fwd Group 1 (and make sure that preset speed 1 is set to the desired speed). Then set the duration of that fwd motion in second. Then set Speed Curve 2 to Rev Group 1. Make sure the number of cycles is set to 1 and the winch should go up for the specified amount of time at the desired speed, go back down and then stop.

IMPORTANT: Note that sometimes, as the blimp goes up, winds aloft might cause the blimp to momentarily stop climbing for a fraction of a second causing the tension between the capsten and the

blimp to go slack for a brief moment. During that time, the lack of tension might cause the line wrapped around the capstan to slip. Therefore, then reeling the line back in during the descent, because of the slippage during the ascent, less line was released than expected and this would result in the more line to be reeled back in thus potentially resulting in the blimp to go lower than the height that it started going up from.

Figure 4-8 Single Phase Power Control Connections



See Recommended Tightening Torques in Table A-2.

*Optional components not provided with control.

Notes:
1. See Table 4-6.
2. Use same gauge wire for Earth ground as is used for L1, L2 and N.
3. Metal conduit should be used. Connect conduits so the use of a reactor or RC Device does not interrupt EMI/RFI shielding.
4. See Line/Load Reactors described previously in this section.

Table 4-9 Single Phase Rating Wire Size and Protection Devices - 120/240VAC Controls

HP	120VAC Single Phase Input				240VAC Single Phase Input			
	Input Amps	Input Fuse (Amps) Fast Acting	AWG	mm²	Input Amps	Input Fuse (Amps) Fast Acting	AWG	mm²
1	12	20	12	4.0	6.3	12	14	2.5
2	20	30	10	6.0	10.2	20	14	2.5
3	30	35	10	6.0	14.4	25	12	4.0

Note: All wire sizes are based on 75°C copper wire. Recommended fuses are based on 40°C ambient, maximum continuous control output and no harmonic current.

1) Power Connector: Blk - Live; Wht - Neutral; Grn - ground.
2) Motor Controller: Blk wires to L1; Wht wires to N.
3) Motor Brake: Blk-1B-3B; Wht-2B-4B
4) Brake/Clutch PS: Blk-1-4; Wht-3-6

1) Power Connector: Blk wire to Live; Wht - Neutral or 2nd live.
2) Motor Controller: Blk wires to L1; Wht wires to L2.
3) Motor Brake: Blk-1B; 3B-4B; Wht-2B
4) Brake/Clutch PS: Blk-1; 3-4; Wht-6

Tether:

The tether used with the winch is a high strength very low stretch braided rope manufactured using Vectran LCP (Liquid Crystal Polymer) high modulus synthetic fiber yarns. This torque-free rope is popular in application when strength, low stretch, heat resistance, and zero creep in fiber are required. The tether is braded with 12 individual vectran ropes.

The braided Vectran 12-strand rope nominal diameter is 1/8" and its approximate weight is 0.9 Kg/100m (0.64 lbs/100ft) while its tensile strength is 2,800 lbs (12.6 N). The tensile strength is determined in accordance with cordage institute 500 Test methods for fiber ropes.Note that the rope strength will decrease after use due to heat, abrasion, ultraviolet or chemical use. The tensile strength might be further reduced by up to 50% as a result of knots or kinks.

12 Data processing and calibration

13 Blimp/Aerostat

The TLS uses two different types of lifting platforms depending on the weather conditions. Three requirements that are critical to optimal insitu measurements with the TLS turbulence payloads are:

1/ platform stability,

2/ lifting capacity,

3/ high windspeed operation capabilities.

Platform stability is required to prevent the turbulence from swinging erratically. Given that a turbulence payload weighs about 1.8 kg, enough lift is required to lift a minimum of two turbulence payloads (including the weight of the line) while permitting ascent rates of at least 1 m/s. Lastly, the TLS needs to be capable of operating in winds of up to 20 m/s.

The two platforms of choice are an aerodynamic blimp, manufactured by the blimpworks company, and a kite/balloon hybrid system called the helikite from Allsopp inc.

The aerodynamic blimp is the preferred platform for operations in calm weather with winds of 10m/s or less. This design will indeed not be able to sustain the strain generated by winds of 15 m/s or more. In such high winds, the stress imposed on the three fins of the blimps become too strong and will result in either the fiberglass rods holding the shape of the fins to reach their breaking point or the knobs that the guy lines of the fins to be dislodged from the blimp. Once one of the fins fails, the blimp will become highly non-aerodynamic resulting in the combination of a very large drag coefficient and a non symmetrical cross section causing the blimp to shake erratically and to come down as the wind pushes it down. The lifting capabilities of the blimp almost all come from its buoyant properties and has very little aerodynamic lift. The advantage of this design is that the highly aerodynamic shape of the blimp maximizes platform stability. Additionally, the blimp also a very small cross sectional area and drag coefficient in the direction of the wind thus allowing the blimp to be raised virtually vertically above its launch point (the winch) and this favoring the collection of vertically profiles. The main drawback is however that the blimp can only be flown in wind conditions of 15 m/s or less.

The helikite system is a much more robust platform than the aerodynamic blimp as it is deployable in winds of up to 50 mph. Being an hybrid design between a balloon and a kite, the helikite benefits from both net buoyant and aerodynamic lift. One of the drawbacks of this system is however it much higher price tag for similar buoyancy lift capabilities. However, because this system is to be used in windy

conditions, the added lift from aerodynamic lift of the wing surface of the kite compensates for the lack of net buoyant lift.

Both systems come in different sizes. A summary of properties for both systems is outlined in the table below:

	BlimpWorks 21’ Aerodynamic Blimp	BlimpWorks 25’ Aerodynamic blimp
		
Length	21’ (6.4m)	25’ (7.62m)
Diameter	7’ (2.1m)	8’7” (2.6m)
Volume	430 ft^3 (12.2 m^3)	787 cubic feet (22.3m^3)
Net Lift (0m/s)	16.5 lbs (7.5 kg)	23.7 lbs (10.7kg)
Max WS	33.6 mph ; 15 m/s ; 29.2 kts	33.6 mph ; 15 m/s ; 29.2 kts
Price (02/2012)	$1863	$3062

	Helikite 7m^3	Helikite 11m^3	Helikite 16m^3
			
Length	11’ (3.35m)	12’ (3.65m)	13’ (3.96m)
Width	9’ (2.74m)	10’6” (3.23m)	11’6” (3.5m)
Volume	247 ft^3 (7m^3)	388 ft^3 (11m^3)	565 ft^3 (16 m^3)
0 mph lift	7.7 lbs (3.5 kg)	12.1 lbs (5.5kg)	17.6 lbs (8.0kg)

15 mph lift	22 lbs (10 kg)	26.4 lbs (12 kg)	35.2 lbs (16 kg)
Max WS	42 mph ; 18m/s ; 36.5kts	45 mph ; 20.1 m/s ; 39.1 kts	46 mph ; 20.6 m.s ; 40 kts
Price (02/2012)	$3321	$4744	$6010

Lift Requirements for minimum of 1 m/s ascent rate at 300m as a function of payload and lifting platform:

Net_lift (NL) = Buoyancy Lift – Balloon Weight = (density_O2-density_He) x Volume

= Spec Given by manufacturer

Residual Lift (RL): amount of xtra lift that permits the ballon to rise (if Res_Lift = 0, balloon is at equilibrium)

RL = NL – Payload – Tether

Payload: the weight of your payload to be suspended

P_1package = 1.8 kg

P_2packages = 3.6 kg

Tether: Weight of the tether (function of height): Vectran tether = 0.9 kg/100m

At 300m,T_300m = 2.7 kg

Ascent Speed Va:

Va = R g / (0.5 Cd A density_O2)^(1/2)

A = Pi r^2

Cd_sphere = 0.25

Helium requirements

Lighting

Cut-down device

14 BOM